

A FEASIBILITY STUDY OF USING HF GROUNDWAVE RADAR FOR
SEA ICE AND ICEBERG DETECTION:
EVALUATION OF AN HF ANTENNA AND DATA COLLECTION OF OCEAN SPECTRA

by

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C-CORE

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The Centre for Cold Ocean Resources Engineering (C-CORE) was established at Memorial University of Newfoundland in St. John's in 1975. Its initial funding was provided by the Devonian Group of Charitable Foundations of Calgary. Ongoing funding now comes from government and industry.

The Centre's mandate is to undertake research that will assist the safe and orderly development of Canada's resources in cold and ice frequented oceans.

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**A FEASIBILITY STUDY OF HF GROUNDWAVE RADAR FOR
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1.0 INTRODUCTION

Offshore development and shipping in Canada's northern and ice infested waters require operation in a very harsh environment. Hence there is a need for sound design, quality construction and well thought out contingency planning. The contingency plan must deal with operation and survival under extreme weather conditions, taking corrective action for sub-system failure and providing effective procedures to abandon an offshore site under total system failure. The function of an integrated forecasting system is to provide the necessary lead time to take appropriate action when weather or ice conditions become critical. The goal is an optimum control between being too daring and overly cautious.

Active remote sensing systems such as radar are deemed superior methods for monitoring ocean surface conditions locally and globally because of the high probability of encountering low visibility and storms offshore; factors which serve to reduce the effectiveness of passive radiation and airborne sensors. A radar system which operates in the HF-VHF (HF denotes high frequency, 3-30 MHz; VHF denotes very high frequency, 30-300 MHz) bands has significant technical attributes for applications to ocean remote

sensing. A Doppler system based on groundwave electromagnetic (EM) propagation, has a potential 100 km range over which it can measure ice and iceberg speeds.

In addition, the identification of ice type based on phase coherent information in the backscattered signal holds promise. Since the backscattered signal would be strongly dependent on the electrical properties of the target, and salinity is a large determining factor of the electrical properties of ice, the backscatter would be related to salinity. Salinity is an indication of the age of the ice; first year ice is more saline than multiyear for example. Also salinity is considered an important parameter in the determination of ice strength. However, at this stage it can only be said that this may permit the sorting of ice types into broad categories.

The chief disadvantages of such a system include the price paid for resolution. Since this generation of radar is in its early phase of development, most of the answers to questions involving the scientific and technical details are speculative, requiring further research before firm engineering commitments are possible.

The fieldwork and data compilation executed under DSS Contract #OSS82-00092 represent only one component of a much broader and longer investigation of ocean and ice feature remote sensing by terrestrial based radar systems operating at HF frequency. The technical objectives of the contract were two-fold:

- (1) To field test the performance of a 24 element fixed (nonsteered) phased antenna array at HF (25.4 MHz),
- (2) To collect a data set of HF backscatter from an ocean radar range where the sampled cells were well defined in range and azimuth.

The experimental site was established at Northern Bay Sands Provincial Park north-west of St. John's. The antenna hardware was assembled on the beach. The site was maintained for 12 days including set-up and demobilization. The initial focus was to evaluate the antenna performance by mapping the beam pattern. After the antenna pattern was established a series of data collection intervals followed to sample HF ocean backscatter for different wind, wave and surface current conditions.

This report will address the scientific basis for the research and the technical detail of the experimental portion. The Tables and the Appendices will serve as the data report for this experiment cataloguing the magnetic tapes of the radar returns (ocean backscatter) as well as waverider buoy data (ocean wave height).

2.0 OCEAN REMOTE SENSING AT HF

The HF radar system should not be considered to be a version of present day marine radar. Although it might share similar operational functions, the basic physics of the interaction process is radically different as is the resultant information gathered. At 25 MHz the EM wavelength is approximately 12 m. If

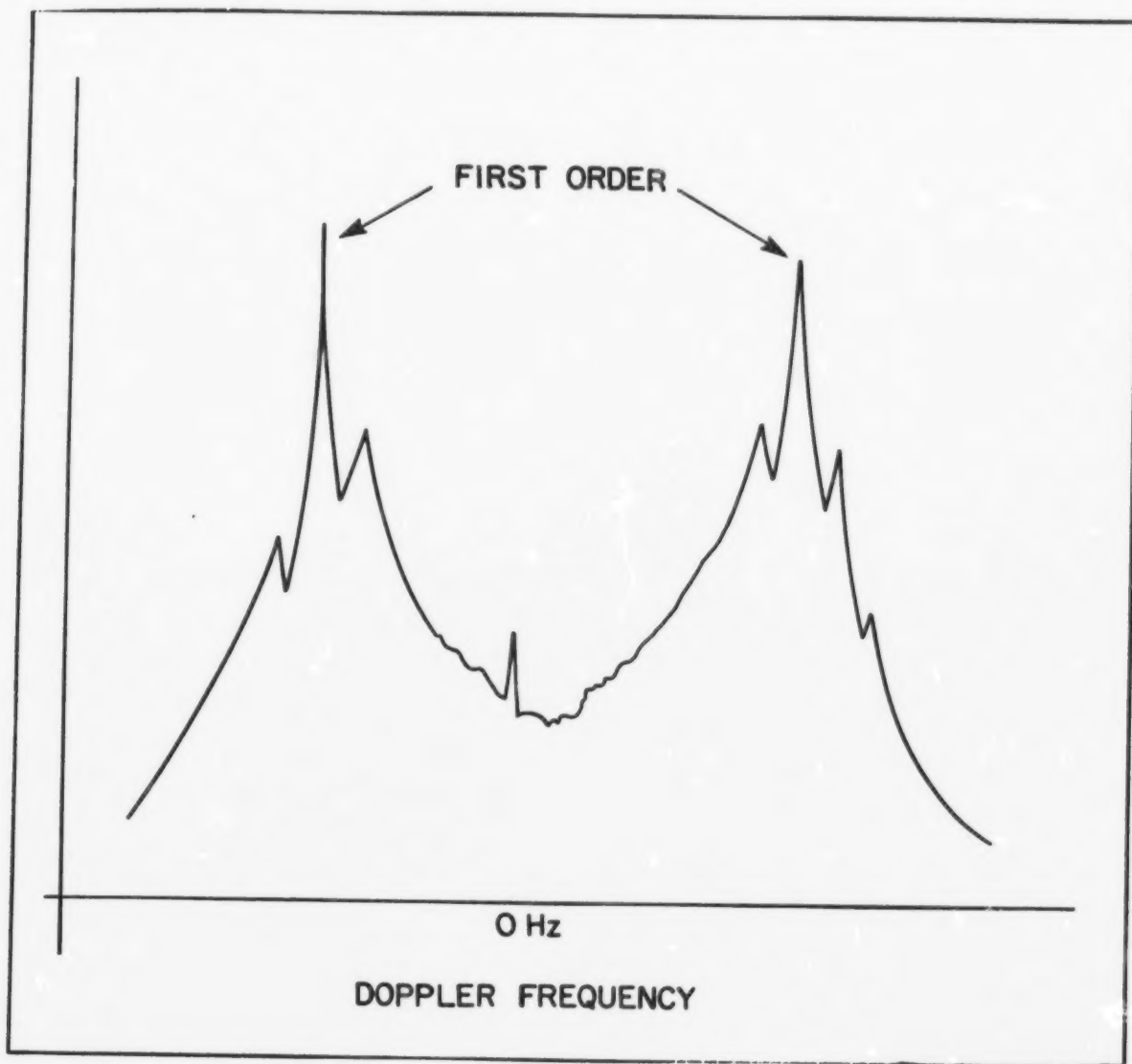


FIGURE 1. An idealized Doppler spectrum plot of received energy versus frequency shift illustrating the two energy spikes representing first order return.

the ocean is illuminated by a 25 MHz EM groundwave then the ocean wavelength component at 1/2 of the carrier EM wave, 6 m, results in what is termed "Bragg" scattering. i.e. Physically a patch of the ocean surface acts like a $\lambda/2$ diffraction grating for HF illumination causing the energy to scatter constructively. Some of this backscattered energy will always return along the original path of transmission. This phenomenon is usually called the first-order scattering and provides a well defined signal at the radar receiver. Additionally there is higher order scattering which can provide further information about the ocean surface condition. Since the ocean surface is composed of travelling waves the backscattered signal is also Doppler shifted with respect to the radar and the Doppler frequency spectrum of the backscattered radar signal shows a pair of dominant energy peaks which correspond to the phase velocity of the ocean waves toward and away from the radar. Figure 1, gives a sketch of an idealized Doppler spectrum. The expected Doppler shift of the first order peaks is well established in wave physics by the wave length of the ocean wave with phase velocity,

$$V_{ph} = \sqrt{\frac{g L_w}{2\pi}}$$

where g represents acceleration due to gravity and L_w the wave length under consideration. Any measured difference from the expected shift is contributed by an additional gross surface transport, i.e. surface current, relative to the radar. One of the initial groundwave HF radar systems was developed with this aspect in mind. CODAR or Coastal Ocean Dynamics Applications

Radar (a research product of the Wave Propagation Laboratory of the National Oceanographic and Atmospheric Administration, NOAA) was designed to measure surface currents. It is interesting to note that some effort has also been focussed on developing a transponder tracking package for use with this radar system.

At C-CORE, we concluded that this equipment, developed at NOAA, represented the state-of-the-art in HF radar. We therefore initiated a technology transfer of the CODAR system to the Canadian community as the first phase of the HF research project. We are confident that we have completed this function and we are now prepared to assist in making this current measuring and mapping technology available to other Canadian research groups for rigorous assessment.

2.1 Oceanographic Applications

System development to support oceanographic research is not the main thrust of C-CORE's proposed program but we are very interested in fostering ocean and coastal applications. Our present project includes surface current measurement in support of an iceberg detection research program executed during June and July 1983. We look forward to possible comparison tests with the BIO's Lagrangian drifters, and a possible circulation study of Arctic channels in 1984. C-CORE plans to provide the complete ocean engineering survey capability. Future programs would be developed in close collaboration with each research group for their input to the detailed specification of a program.

2.2 Sea Ice Detection and Tracking

The potential application of this type of radar system to monitor ice conditions is C-CORE's main research incentive. Inadvertently, we encountered partial ice cover during a recent field experiment at Cape Race Nfld. which was originally planned as an oceanographic demonstration of the radar system. Hence, for the first time in the Canadian Offshore a CODAR system has operated with sea ice in its field of view. Initial interpretation suggests that the first skin of new ice (identified as ice type - nilas) is sufficient to reduce significantly the wind wave component which acts like a diffraction grating at 25 MHz. A layer of Nilas can form after a few hours of below freezing temperatures on an ocean surface far removed from the main pack. Therefore suppression of the Bragg peaks is not a good indicator of an imminent serious sea ice cover.

The theoretical model utilized for the analytical treatment of scattering of EM groundwave propagation by ice features is illustrated graphically in Figure 2. The mathematical treatment of EM scattering is very involved and is reported by Walsh (1983). The surface EM wave can be thought to adhere to the boundary between sea and air. The EM waves under consideration were vertically polarized, when they emitted from the transmit antenna. The electrical, E, component of the groundwave takes on a wave tilt and hence there is a horizontal component of the electric field in the direction of propagation. While travelling over a highly conductive surface like sea water the wave tilt is small.

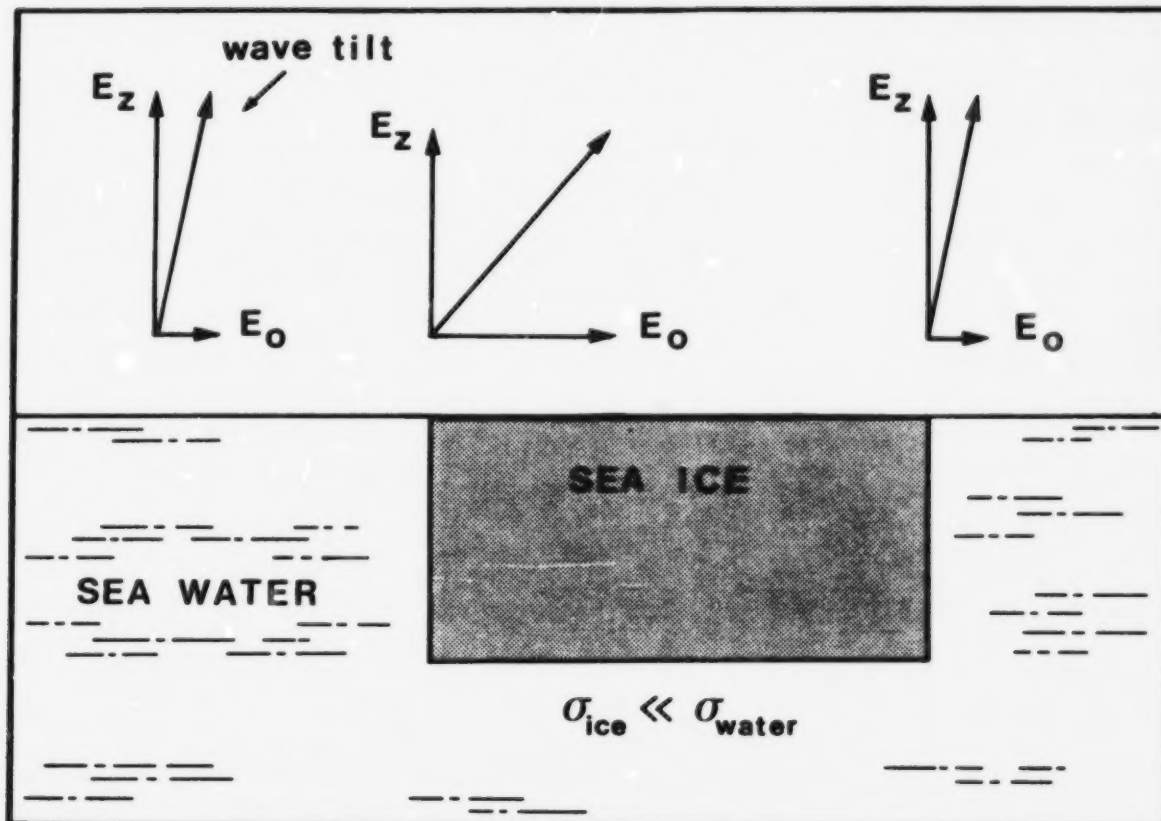


FIGURE 2. A pictorial treatment of a vertically polarized HF groundwave propagating over sea water and the discontinuous shift of the wave tilt when the wave encounters an electrically discontinuous boundary. These boundaries serve as scatters of some of the transmitted energy where σ represents conductivity.

When the advancing wave encounters a discontinuity in electrical properties of the surface, moving from ocean to ice and from ice to ocean, the wave tilt undergoes a discontinuous jump and such jumps scatter some of the propagating energy. If the scattering is strong enough and the receiver has high enough sensitivity, a portion of the scattered signal will be measured at the radar receiver location. The strength of the scattered signal will be proportional to the length of the discontinuity encountered. In practical terms this will establish how small a target can be detected. This scattering process from an edge discontinuity is in contrast to the ocean backscatter considered initially where the return energy is a power density integrated over the sampled region.

In terms of theoretical limits, the minimum target of detectable size will depend on the interaction of the EM wave length with a particular discontinuity (ocean/ice) geometry. In engineering terms this will also require consideration of sensitivity, path loss, transmit energy, and modulation characteristics which are of course all linked to different strategies for signal processing.

There are various ice conditions for which identification and characterization with a remote sensing system will aid offshore operation and maintenance of shipping routes. The system should detect icebergs and give information on their velocity and size. It should allow tracking of the ice edge and provide the edge velocity with each sample. It would show lead water beyond the ice edge or down range into the ice cover. Information on down

range open water is of value to transitting vessels in the selection of optimum routes and to platform operators in evaluating the extent and potential for pressure field (stress) from an incident ice cover. The requirement to transmit the EM carrier wave beyond the first ocean/ice boundary raises the topic of HF propagation over a surface layer of ice and how attenuation depends on electrical properties, frequency and ice thickness. We can presently speculate that this type of system will be able to discriminate between different ice type and provide a statement of the ice properties encountered. The process would find its basis in the varying electrical properties of different ice types. Multi-year and first year ice have very different salt contents hence different conductivities. The same is true for an iceberg embedded in pack ice. These problems will be addressed in our evaluation of this radar technology.

3.0 FIELD TESTING THE HF WIDE APERTURE NARROW BEAM ANTENNA

The experimental work to field test the HF fixed (nonsteered), phased antenna array for its application for ice detection was begun in 1982 and supplied the data of this contract report. The field testing of the fixed phased antenna array over an open ocean range, augments the ongoing research in sea ice and iceberg detection.

It is considered important to have an experimental antenna configuration for the radar system to permit sampling the radar return signal from a series of spatially distinct cells on the ocean surface. This rational enables the collection of the backscattered signal from a homogeneous patch of the sea surface, or from a single iceberg or a small group of ice floes. This particular fixed, phased antenna system can sample the radar backscatter at HF from relatively small cells: 1.2 by 1.2 km. at 12 km down range. A data collection period was included in the schedule to have a set of radar returns from cells of ocean surface which can be considered to contain a homogeneous wave height distribution and a homogeneous surface current. The Doppler spectra collected for each ocean cell along with surface truthing will provide the experimental benchmark for Mr. S. Srivastava's academic research on the analytical treatment of ocean backscatter of HF radiation. His theoretical model predicts the power spectrum of back scatter radiation. (a PhD program of the Faculty of Engineering and Applied Science, Memorial University of Newfoundland.) The results of this analytical

investigation can provide the key ingredient for the identification of a characteristic target signature at HF. The fixed, phased array work and sea state data collection were the two specific objectives of the contracted work. At the conclusion of the report some space will be allotted to give an overview of the objectives and work schedule of the overall HF radar research program and to show how this part of the work relates to the wider scope of the program.

The detailed work involved two studies: (1) the mapping of the fixed, phased receive antenna pattern using a small fishing vessel and (2) a data collection program to record periods of ocean backscatter at HF. The experimental site at Northern Bay is indicated on the map, Figure 3 and will be detailed below. The fixed, phased antenna array will play an important role in the initial sea ice and iceberg research, particularly in the assessment of the radar cross-section of icebergs and ice edges. The studies will also provide the basics for designing the "next" generation of HF antennas for deployment from offshore platforms or vessels.

3.1 The Design Considerations of the Recieve Antenna

A highly directional HF antenna was required to maximize signal strength and angular resoulution. Among the many basic designs of directional antennas which are available, an array of discrete elements, each fed independently is often the best choice for high frequency (HF) applications. The design chosen for the

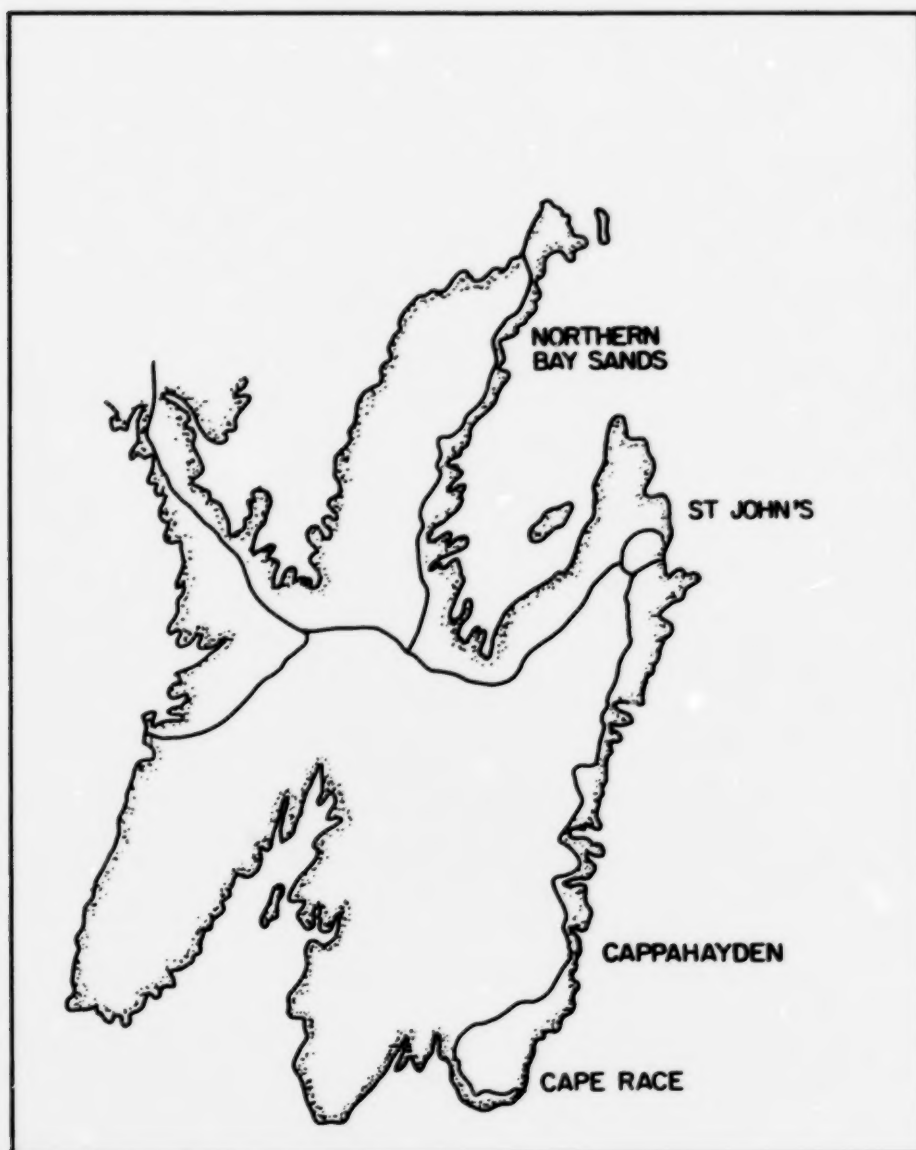


FIGURE 3. Coastal sites on the Avalon Peninsula for the initial series of field trials.

C-CORE antenna is based on a uniform distribution of broadside omnidirectional elements driven with equal currents. The antenna currents are maintained in phase through the cable network to the front end of the receiver. The standard radiation pattern for an untapered broadside array has been described by Jasik (1961) and theoretically this antenna displays a series of tapered side lobe energy patterns with the first sidelobe being 13 dB down from the main lobe.

This theoretical side lobe energy pattern is often only marginally acceptable in an idealized assessment of requirements and is usually not achievable in practise due to nonuniformities produced during construction and installation of the hardware involved. For an application of remote sensing of ocean conditions with a land based HF radar system it is deemed desirable to suppress the energy returned from the side lobes by at least 20 dB. This is somewhat better than the energy separation between the first order 'Bragg' scattering and higher order returns.

To achieve this specification on side lobe suppression, the current distribution must be amplitude tapered at the individual feed points according to a theoretically predetermined 'window' based on the desired antenna performance. There have been many 'window' shapes developed over the years, each having its own special set of advantages and disadvantages for a particular application. For example the exact Blackman 'window' will achieve a -50 dB suppression of side lobes, but results in a 3 dB beam width which is 1.52 times larger than for the basic rectangular array.

The best overall design to provide optimum side lobe energy suppression to beam width ratio is described by the Dolph-Tchebyscheff distribution (Dolph, 1946). It evenly distributes side lobe energy over the full 180 degree symmetrical face of the receiving aperture, rather than concentrating more energy in the mainlobe and thus broadening it.

The C-CORE antenna is made up of 24 omnidirectional 1/4 wave elements whose current distribution is amplitude tapered, with a set of custom built attenuators, following the Dolph-Tchebyscheff polynomial to provide a 30 dB suppression of side lobe energy. The half power beam width is basically described by an empirical approximation of the antenna pattern given by Stegen (1952) where

$$\theta = \frac{A \lambda}{1}$$

A equals 60.6 degrees for side lobe suppressed by 30 dB. For a wavelength, λ , of 11.81 m. at 25.4 MHz and l of 215 m.; the aperture based on 0.81 spacings, the beam width, θ equals $(60.6)(11.81)/215$ which computes to 3.33 degrees. A perspective view of a 24-element fixed phased array is illustrated in Figure 4 and a plan view with the detail for the antenna layout is provided in Figure 5.

C-CORE'S HF FIXED (NONSTEERED) PHASED ARRAY

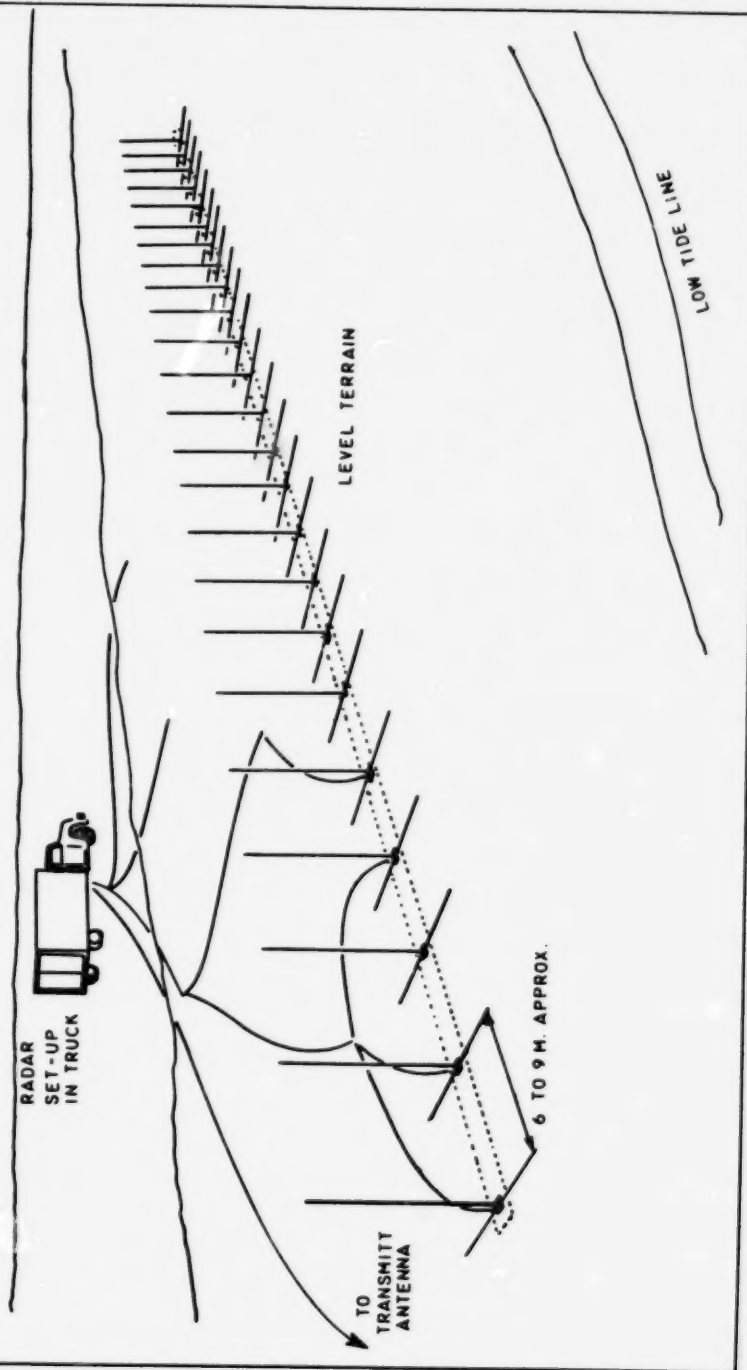


FIGURE 4. 24-Element HF receiving array (perspective).

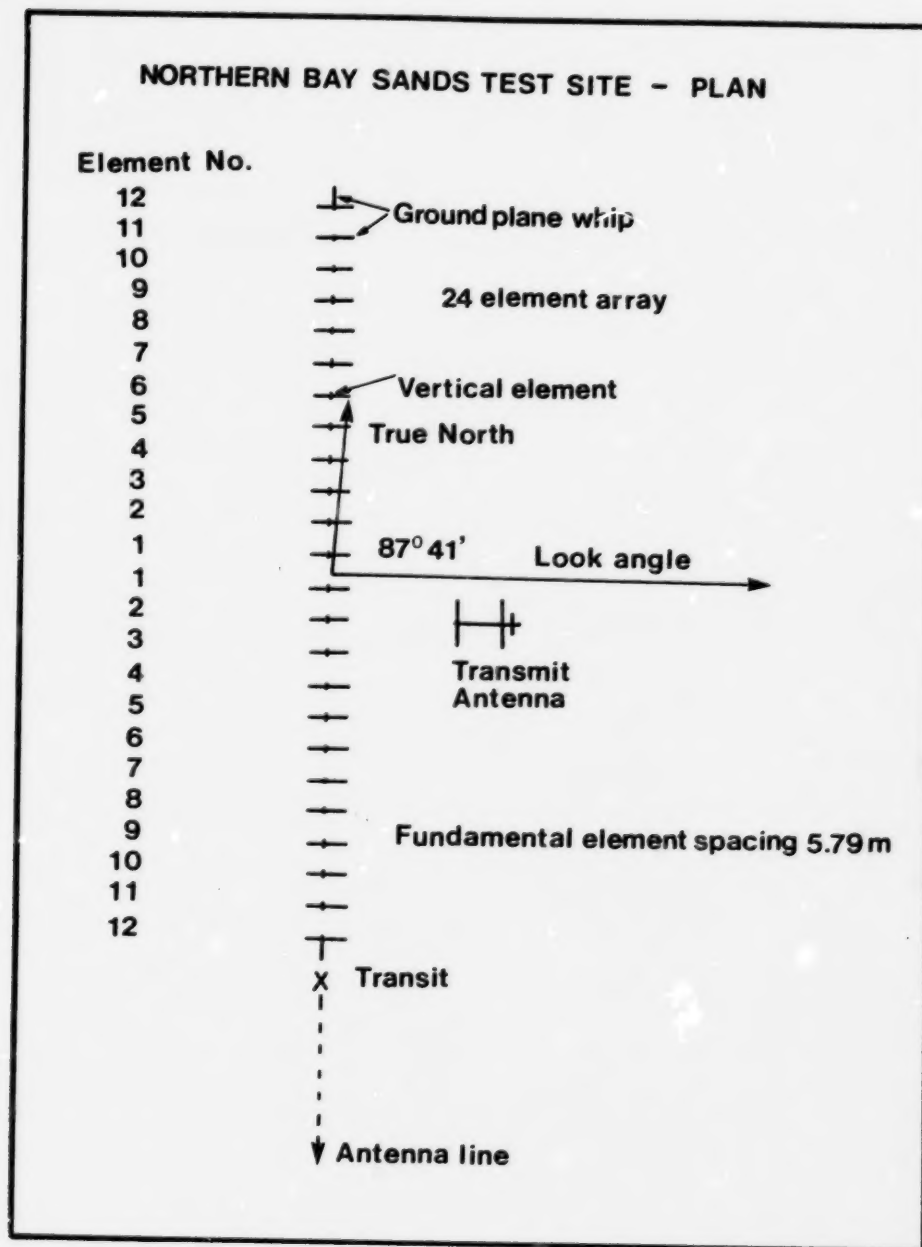


FIGURE 5. 24-Element HF receiving array top view.

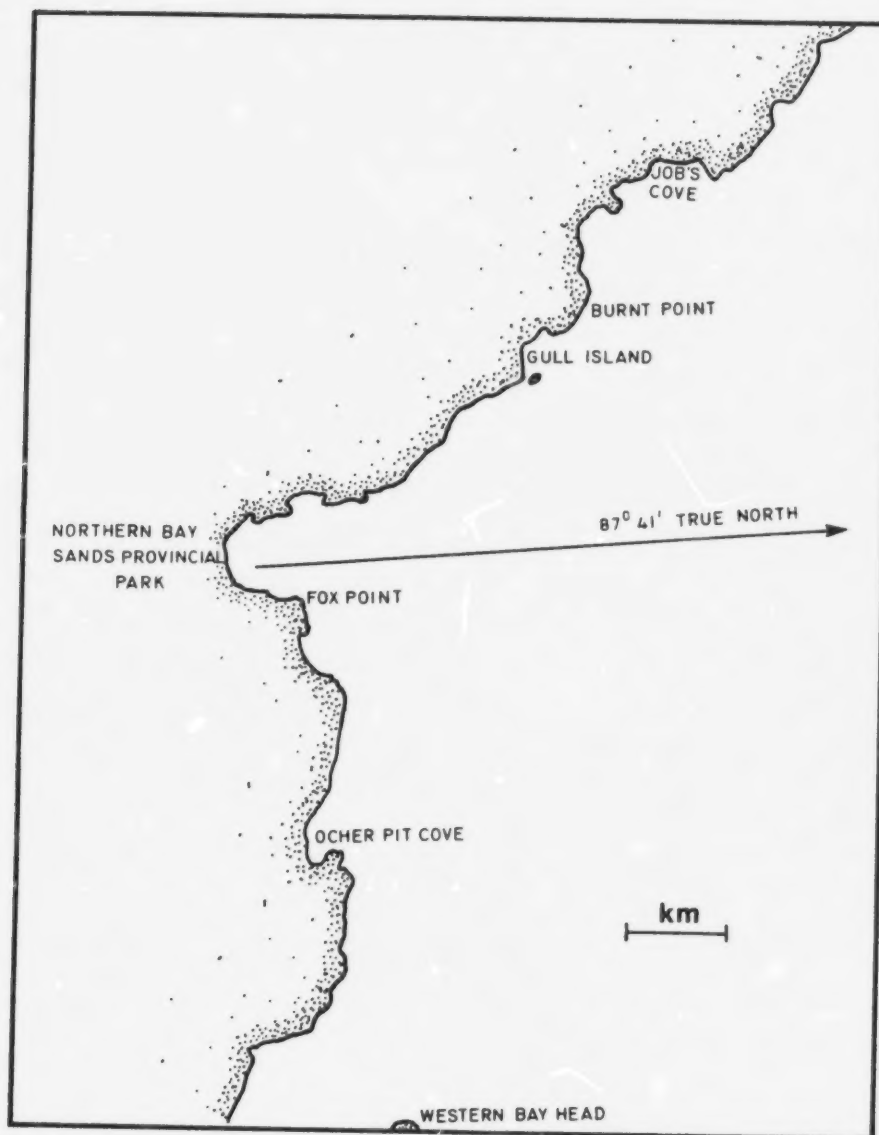


FIGURE 6. 1:50,000 scale map showing seaward look direction of 24-element HF receiving array.

3.2 The Site Description

The field program was run at Northern Bay Sands Provincial Park from October 18, through October 29, 1982. The chronology of events are tabulated in Appendix A. The antenna components were set up on the beach and the radar transceiver, control unit and recording devices were operated from the park's Administration Centre. Figure 6 is a detailed map of the area and gives the line of the look direction of the fixed phased array.

(i) The C-CORE HF (24 element) Fixed, Phased Receiving Array:

The fundamental element spacing was decreased from a proposed 9.45 metres to 5.79 metres because the beach does not run perpendicular to the bay and there was not enough room for the larger spacings. The total length of the antenna was:

$$(24-1) \times 5.79 \text{ m} = 133.2 \text{ metres}$$

The antenna was oriented roughly parallel to the low water line and extended southward from the northern end of the beach. The electrical ground plane was established by laying a metal grid (light weight wire fencing material) along the line of the antenna and weaving the ground radials of each element through the mesh to provide a continuous ground for all the antenna components.

(ii) **Transmit Antenna:**

This antenna, a three element vertically polarized Yagi, was located in front of the array (between the array and the water line) to minimize the power radiated into the receiving antenna by the transmit antenna.

The site was a low profile sand beach and there was concern that the whole beach area would go awash during a storm. The transmit antenna was of single unit construction and could be transported to higher ground when the radar operation was shut down. This same contingency plan was not feasible for the 24-element receiving antenna. The counter-measure activity taken to guard against flooding was to water proof the feed connections. Fortunately there was no problem with storms or flooding during the experimental period. In future deployments the antenna will be placed on higher ground.

3.3 Experimental Methodology

The CODAR Technology Inc. HF transponder was used in both the mapping of the beam pattern and in the measurements of attenuation with distance over sea water of a vertically polarized HF wave.

When activated, the transponder broadcasts a fixed length pulse of fixed power (2 watts) at the frequency of interest. It can therefore serve as a benchmark signal.

3.3.1 Mapping the Beam Pattern of the 24-Element Array

The received signal at the 24 element array was measured while the transponder was moved by boat across the mouth of Northern Bay. The distance between the boat and the centre of the antenna was held constant at 3.0 n. miles $\pm$ 0.1 n. miles (measured with the marine radar aboard the vessel). Since the transponder produced a fixed power output and the range was held constant, the power spectrum of the signal from the transponder at the receive antenna was a function of the azimuth of the transponder relative to the look angle of the receive antenna. A surveyor's transit was used to sight the boat enabling an accurate estimate of the azimuth. The transit was located on the same line as the long axis of the antenna at a point approximately 6 metres south of the last antenna element. The CODAR radar system was configured to collect a two minute time series of the radar return while the position of the vessel was maintained and recorded. Comparison of the received transponder power spectrum, as a function of azimuth, produced a polar map of the relative receive antenna gain with azimuth. The topography limited the mapping of the beam pattern to the azimuths lying within the angle subtended by the centre of the antenna and the headlands on either side of Northern Bay.

3.3.2 Attenuation of an HF Wave with Range Over Sea Water

In order to generate the required radar return to compute the attenuation with range for vertically polarized HF wave propagating over sea water, the incoming power spectrum of the 24 element array was sampled while the transponder was moved outwards on the boat following a heading along the estimated bore sight (look direction) of the antenna.

Since the azimuth is held approximately constant during sampling the power spectrum for the transponder was a function of range only. The transit station was used to direct the course of the boat while it remained within line of sight at the beach. After passing over the horizon the vessel followed a compass course on the established heading.

The CODAR system was set up to collect a two minute time series of the radar return for a number of transponder ranges. Comparison of the received spectrums from transponder as a function of range were to provide a measure of the relative attenuation curve for propagation over sea water.

3.3.3 The Absolute Transponder Position

During the collection of any time series the transponder motion must be minimized to reduce frequency smearing. Therefore the boat attempted to hold its position while each sample time series was collected. During each sample period the distance of the boat relative to three known land references was recorded

using the display of the marine radar. This provided additional positional information on the boat during each charter operation. The measurements of the position of the vessel during each measurement period are documented in Appendix B.

3.3.4 Ground Truthing Ocean Conditions in the Area of Interest

The collection of radar return signal from the ocean test range, in the main lobe of the 24 element array was also scheduled as a part of this field program. The objective was to collect a data base of ocean backscatter from a surface truthed area with measured wave conditions to correlate oceanographic conditions with radar return. The theoretical work supporting this correlation will provide the interpretation methods to derive surface wind speed and direction and an estimate of wave directional spectrum from radar returns.

To establish the ocean conditions encountered, a waverider buoy was installed to collect wave height data at a known position, $46^{\circ} 56' 12''$, $52^{\circ} 59' 48''$ lying within the main lobe of the receive antenna. Wind velocity was also recorded at the position of the waverider buoy using an anemometer whenever the boat was positioned at that location. The catalogue of the waverider buoy data tapes are documented in Appendix C.

3.4 Mapping The Beam Pattern With Normalized Power Spectrums

During the field operation the CODAR system produced normalized power spectrums in the frequency domain from the radar signal it collected in the time domain. After a time series of receive antenna voltage was collected the d.c. component in the time series was removed. This processing caused the zero Doppler (zero Hertz) component of the time series to be removed.

The conditioned time series was then processed through a Fast Fourier Transform (FFT) into the frequency domain. The frequency spectrum was then normalized to the highest component in the spectrum, and displayed in dB, 0 dB, the value of the highest component. Therefore, every other frequency component would be some number of dB down from the highest component.

These normalized spectrums are the usual system output displayed in field operation. Each spectrum represents a 32 second time series and therefore more than one such spectrum can be generated during the field collection of a two minute run.

Two minute time series containing the transponder signal were collected for different transponder azimuths, relative to the fixed phased array's look direction (refer to Experimental Methodology in Section 3.3.1).

In order to plot the relative gain of receiving antenna with azimuth it is necessary to calculate the magnitude of the received signal as a function of the azimuth. This meant comparing the transponder signals from each of the normalized power spectrums relative to some reference signal present in all the normalized

spectrums. It was assumed that the first order sea state components would remain essentially unchanged over the period of measurement and therefore would provide the required constant benchmark in each normalized spectrum. Hence it would then be possible to relate the transponder signals for different azimuths. Table I gives the transponder signal as a function of angle from the boresight and Figure 7 gives the plot of the observed pattern versus the theoretical pattern.

3.4.1 Anomalies in the Observed Beam Pattern

Although the observed beam pattern generally agrees with the theoretical curve for this type of antenna, there are two anomalies in the main lobe, at approximately 357.5° and 1.8° .

Ideally, for data processing with the CODAR system, it is necessary that the transponder be held motionless. Otherwise the transponder's monochromatic signal will be smeared in the frequency domain due to the motion induced Doppler shifts. However, since the transponder was installed on a boat's deck it was unlikely that smearing could be eliminated. In such a case the transponder spike would broaden and therefore decrease in relative amplitude to maintain an equivalent energy under the broadened curve; a clean spike would be observed under stationary conditions.

The observed beam pattern was calculated using the peak values of the transponder spike in a 128 point normalized frequency spectrum generated from a 32 second time series. This

TABLE I

Normalized Beam Pattern Data Calculated From Normalized Spectra

Transit Azimuth (deg)	True Azimuth (deg)	G=[Avg. Power Transponder- Avg. Power first order Sea State] (dB)	Normalized (to Theoretical) Beam Pattern = 31.62x10 (G-Gmax)
333° 04'	333° 44'	-20.0	0.50
334° 53'	335° 33'	-23.5	0.33
338° 53'	339° 35'	-23.5	0.33
340° 57'	341° 39'	-18.0	0.63
343° 00'	343° 43'	-8.0	2.0
344° 52'	345° 35'	-12.6	1.2
346° 25'	347° 08'	-22.5	0.38
347° 42'	348° 26'	-20.7	0.46
348° 29'	349° 13'	-14.5	0.94
349° 48'	350° 32'	-11.3	1.36
351° 27'	352° 11'	-6.2	2.45
353° 08'	353° 52'	1.0	5.62
355° 10'	355° 54'	9.8	15.5
356° 51'	357° 35'	8.3	13.0
359° 40'	0° 25'	16.0	31.62
1° 05'	1° 50'	9.3	14.6
2° 44'	3° 29'	15.0	28.2
3° 46'	4° 30'	5.1	9.0
6° 44'	7° 28'	-1.0	4.46
8° 01'	8° 45'	-9.4	1.70
8° 51'	9° 35'	-9.9	1.60
11° 11'	11° 55'	-12.9	1.13
12° 15'	12° 59'	-7.3	2.16
15° 02'	15° 45'	-14.4	0.95

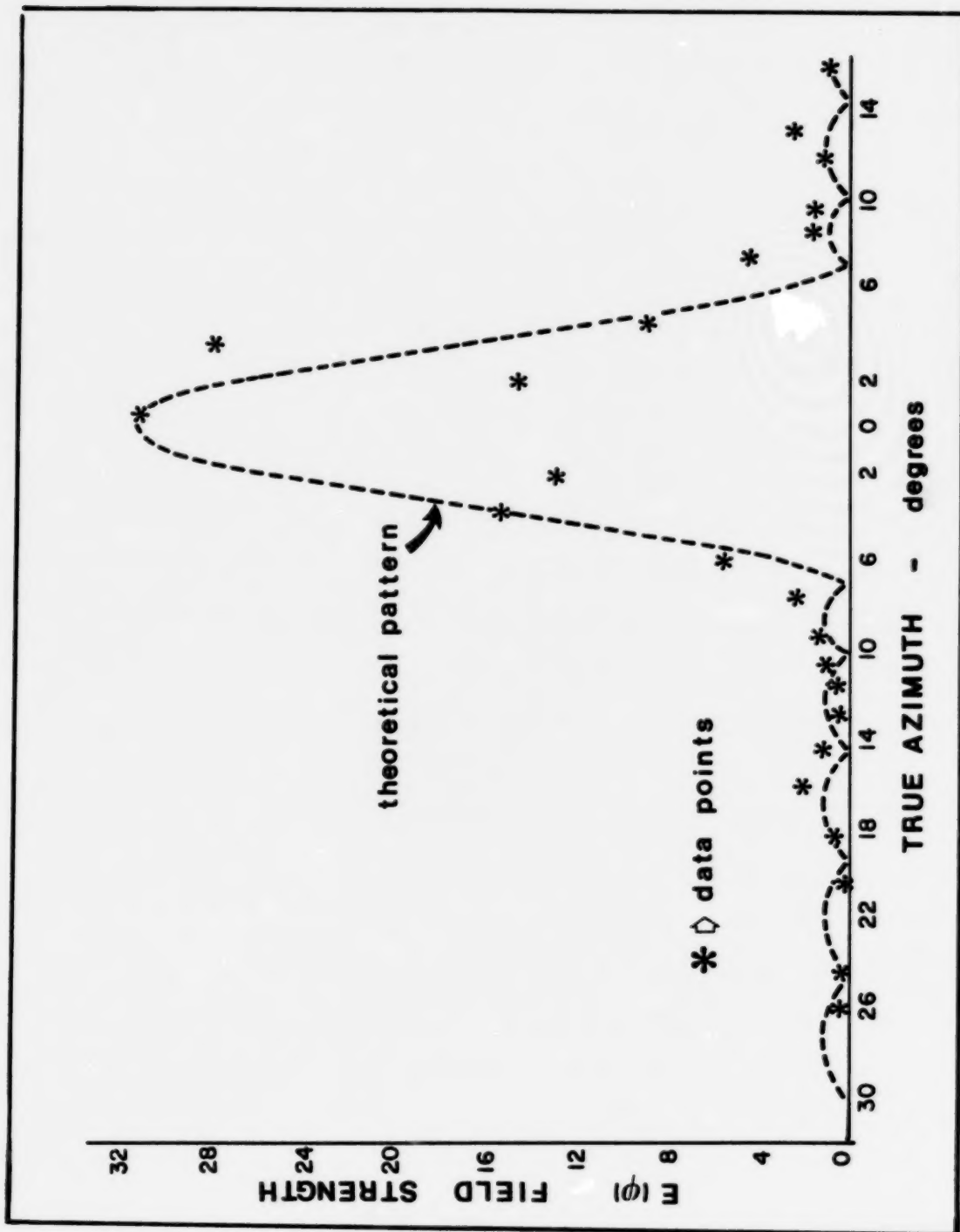


FIGURE 7. Normalized receive antenna field pattern. Observed versus theoretical. Based on peak values of transponder.

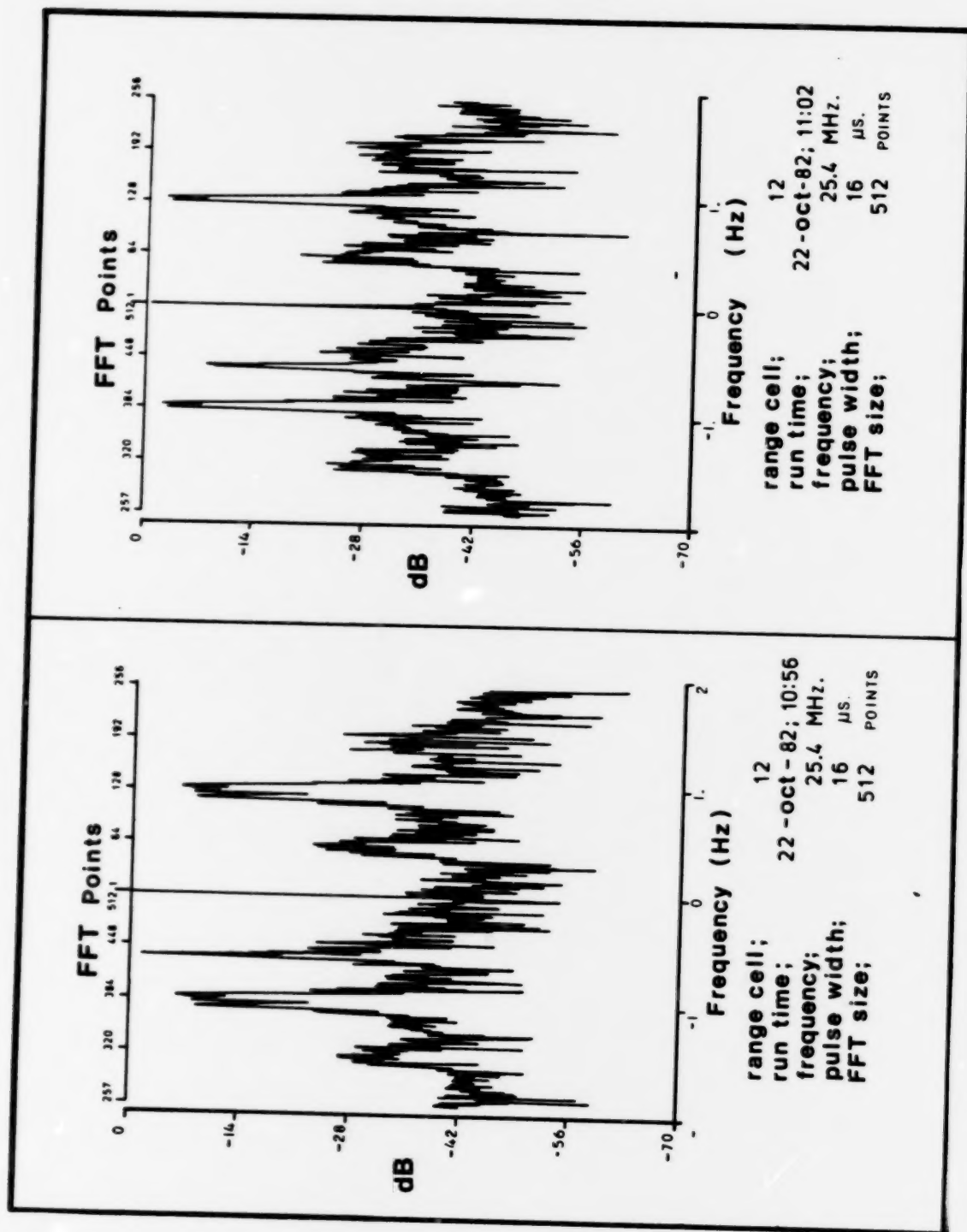


FIGURE 8. Normalized power spectra containing zero doppler at receive antenna azimuths 1.8° , 0.4° .

processing would no longer be valid if the degree of smearing became significant. In such a situation it would be necessary to consider the energy under the curve, not the peak value.

This was precisely the argument put forward to explain the anomalous points. After the experiment was finished, the CODAR software was used to reprocess some of the radar runs to produce frequency power spectrums which retained the information at zero Doppler. In the subsequent processing, the full two minute time series were used to generate the spectrums, giving a more complete history of any motion induced Doppler.

Referring to Figure 8, (normalized power spectrums containing zero doppler at receive antenna azimuths 1.8° , 0.4°), the transponder frequency returns are centred around FFT points 128 and 384. First order sea state returns appear at 436 and 76 (buried in second order returns).

It can be seen immediately that the transponder returns from 1.8° contain more Doppler spread than those at 0.4° . This explains the abnormally low peak values at 1.8° and the cause of the apparent anomaly in the pattern observed in the antenna field calculations.

A more accurate field pattern is obtained by integrating the power under the transponder peak, and plotting energy versus azimuth. Numerically integration corresponds to the summing of all power contributions, one contribution for each discrete Doppler frequency underneath the transponder return. Referring again to Figure 8, the power of the transponder at $1.8^{\circ}50'$ is a spread of 24 Doppler frequencies from channel 116 to 140.

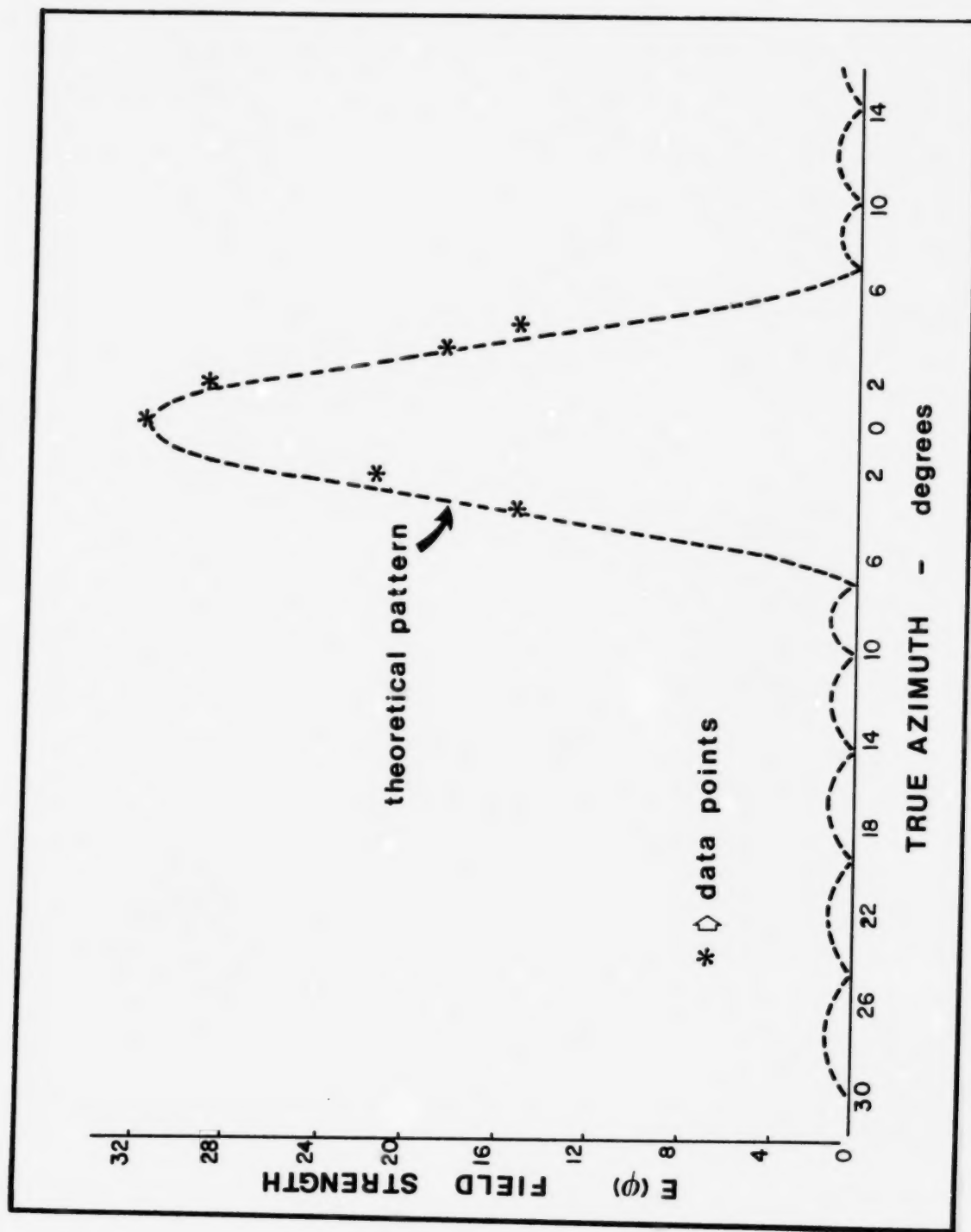


FIGURE 9. Normalized receive antenna field pattern recalculated using energy under transponder signal.

Therefore the energy under the transponder curve is approximated by

$$E(v) = \sum_{j=116}^{140} v_j^2$$

where V_j is the complex voltage at the Doppler frequency corresponding to channel j . The un-normalized Doppler voltages from each spectrum had to be dumped from the data tape in order to perform these calculations. Points in the main lobe were recalculated in this manner and the highest point was 31.62. The other five points were then normalized to the highest point.

The results are given below in terms of azimuth and field strength.

Azimuth	Normalized Field Strength
4° 30'	14.95
3° 29'	18.27
1° 50'	28.74
0° 25'	31.62
357° 35'	21.11
355° 54'	10.32

Plotting these points in the same manner as Figure 7 results in the graph of Figure 9. These points now indicate that the

observed field pattern is in close agreement with the theoretical description of the lobe.

In future work, when using field strength of the transponder return to map the antenna pattern, the necessary calculations will be carried out with the un-normalized power spectrum to provide the more reliable result. Although the normalized power spectrum is a valuable indicator during field operation, it breaks down in attempting an accurate delineation of the antenna boresight unless a better fixed reference within the spectrum can be established.

3.4.2 Attenuation Over Sea Water

The estimation of the relative attenuation over sea water with range (see Section 3.3.2) was derived indirectly by calculating the power spectrum of the transponder for twelve different locations, from one to twelve nautical miles in steps of one nautical mile. This exercise involved having the boat carry the transponder seaward along the direction of the boresight. A station was established every nautical mile to permit the collection of a two minute time series which included the transponder return signal. The frequency spectrums of the two minute voltage time series were used to estimate the energy under the transponder signal in a manner similar to the method applied to recalculate the field pattern of the main lobe (see Section 3.4.1).

Since the gain curve of the radar amplifier was constant with range for the test and the transponder was positioned on or near the boresight direction, the observed transponder energy was expected to vary in proportion to the changing path length (range) over sea water. The attenuation based on computing the transponder energy, using the two minute time series with all energies normalized to the energy at one nautical mile, did not however, produce an acceptable result.

The losses although generally decreasing with range did not fall off smoothly as would be expected. The variance appears to be larger than the deviations which might be explained by experimental error. The data has been re-examined, and the spectrums computed for different range resolutions. The numbers do not change appreciably.

The range run data was collected prior to identifying a bad attenuator and one problem element in the 24-element array. These circumstances would broaden the receive antenna beam width and therefore the azimuthal position of the transponder should prove less critical.

Nonetheless it is possible the transponder was positioned on the steep slope of the beam pattern gain; refer to the theoretical curve in Figure 7 or 9. Therefore a small deviation, one to two degrees in azimuthal position, could result in a significant change in receive antenna gain.

The attenuation with range will be replicated in June 1983 when C-CORE will be making a similar set of measurements over the Strait of Belle Isle.

3.5 Summary of Field Work

(1) The fixed (nonsteered) phased antenna array produced the expected beam pattern and hence can provide an experimental method to sample relatively small patches of ocean surface, 1.2 by 1.2 km at 20 km range. This will allow the collection of radar backscatter from homogeneous ocean samples and from well defined iceberg and sea ice targets.

(2) Moving the CTI transponder through the down range area proved a successful technique for mapping the antenna gain pattern. The plot of signal strength versus angle showed the boresight to be 1.8° clockwise of the surveyed direction. It will be important to establish the antenna pattern when setting up to measure the cross-section of an iceberg to ensure the iceberg is actually in the footprint of the radar.

(3) The field experiment provided a data collection component to support the research program on the analytical treatment of ocean backscatter (Srivastava and Walsh, 1983).

4.0 THE EXPERIMENTAL PROGRAM FOR THE HF RADAR RESEARCH

4.1 Technology Transfer of the HF Radar System

The phase of the program we have titled 'The Technology Transfer' was completed by March 31, 1983. This has involved the purchase of a single CODAR unit and the acquisition of the associated software and operator skills to get the system up and running. This work has been supported to date by industry and government grants to C-CORE and by government sponsored research contracts. In February, 1983 we ran a two site CODAR experiment at the southern Tip of the Avalon Peninsula (see Figure 3 for radar stations at Capphayden and Cape Race) to demonstrate operational capability as well as to map the surface currents over the Ballard Bank. The work has involved considerable development of control and interpretive software for our basic system. At present the commercially available radar equipment is still in a development state, in many respects. From our experience we have a number of ideas for engineering modifications to produce a more user oriented package. We have run three field tests for current measurement from coastal sites as part of this year's work.

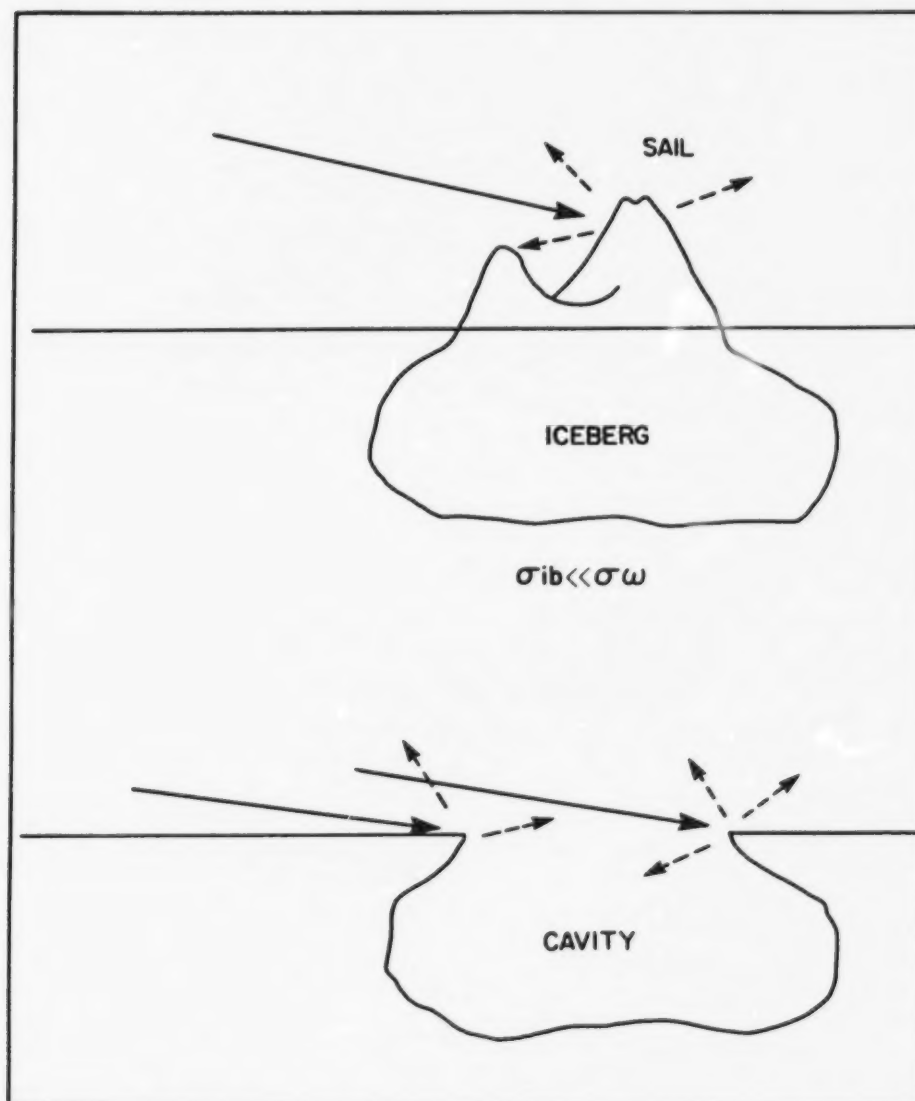


FIGURE 10. A pictorial treatment of an iceberg and an iceberg cavity scattering the energy of a vertically polarized HF transmission where σ_{ib} and σ_w represent conductivities of iceberg and sea water respectively.

4.2 The Detection and Tracking of Sea Ice and Icebergs

The fundamental questions to be addressed in our planned experimental program have been introduced. An iceberg detection experiment is planned for June 1983 at the eastern entrance to the Strait of Belle Isle. A pictorial treatment of how an iceberg and the cavity resulting from the underwater portion of the iceberg will serve to scatter the energy of an HF transmission are given in Figure 10. The map of Figure 11 shows the area selected for the experiment. The fixed phased array antenna will be directed northward across the Strait and there is a high probability that a number of icebergs will cross the field of view during the experiment. In 1982, in excess of 80 icebergs were tracked by Coast Guard's mobile Vessel Traffic Management (VTM) trailer set up at Cape Norman. The VTM trailer will be in operation at Cape Norman again in 1983 and the iceberg drift records collected at the trailer will be available to support our proposed program. The work plan includes recording the size and shape of the icebergs observed. Some iceberg drafts will also be measured with an ice sounding impulse radar. The two site CODAR system will be operated simultaneously with the iceberg detection experiment to monitor surface currents for correlation with the iceberg tracks.

A cross loop antenna, one possible solution to the need for a compact HF antenna to deploy this remote sensing technology from an offshore structure, was originally proposed as an integral part of the Master Site operations. It would have been tested for both mapping of surface currents and for application to iceberg

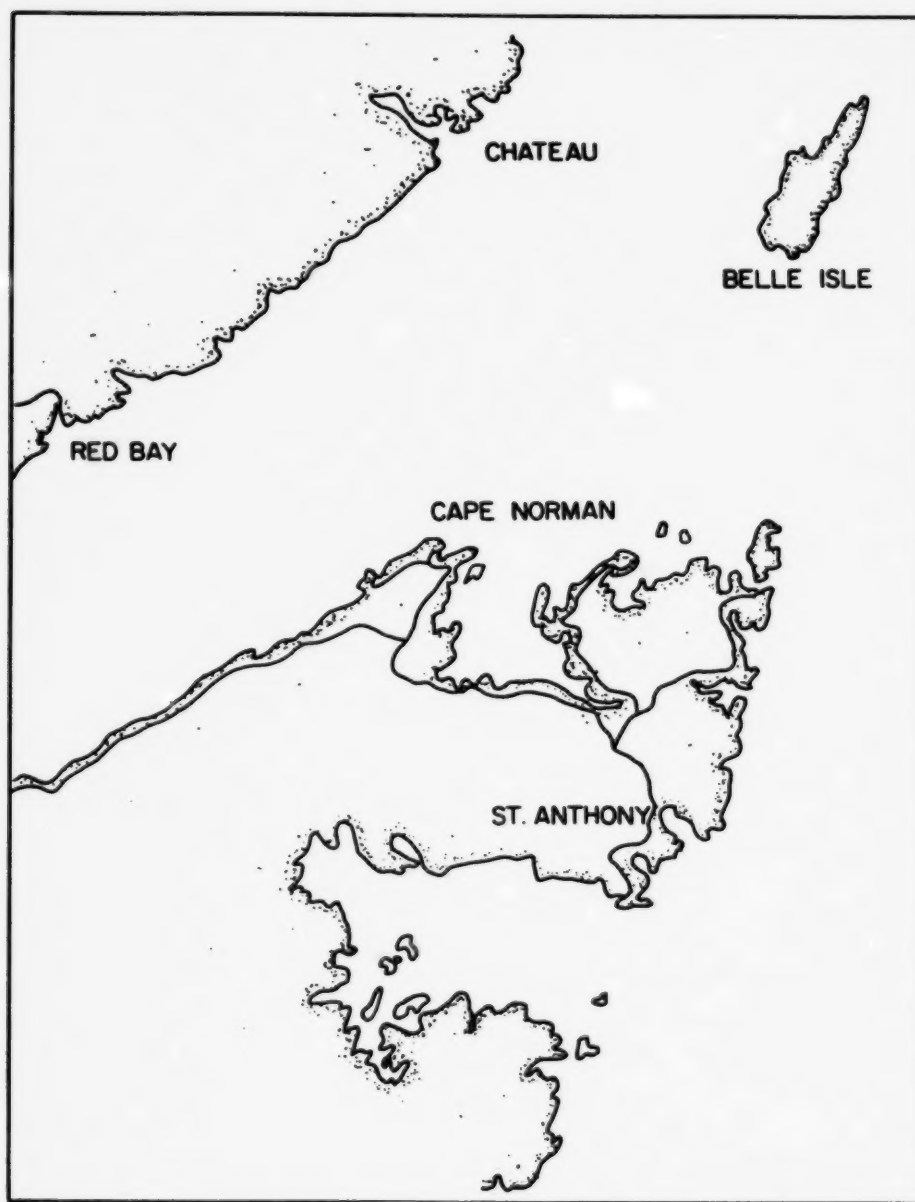


FIGURE 11. Map of the eastern approaches to the Strait of Belle Isle, the designated site for the iceberg detection experiment.

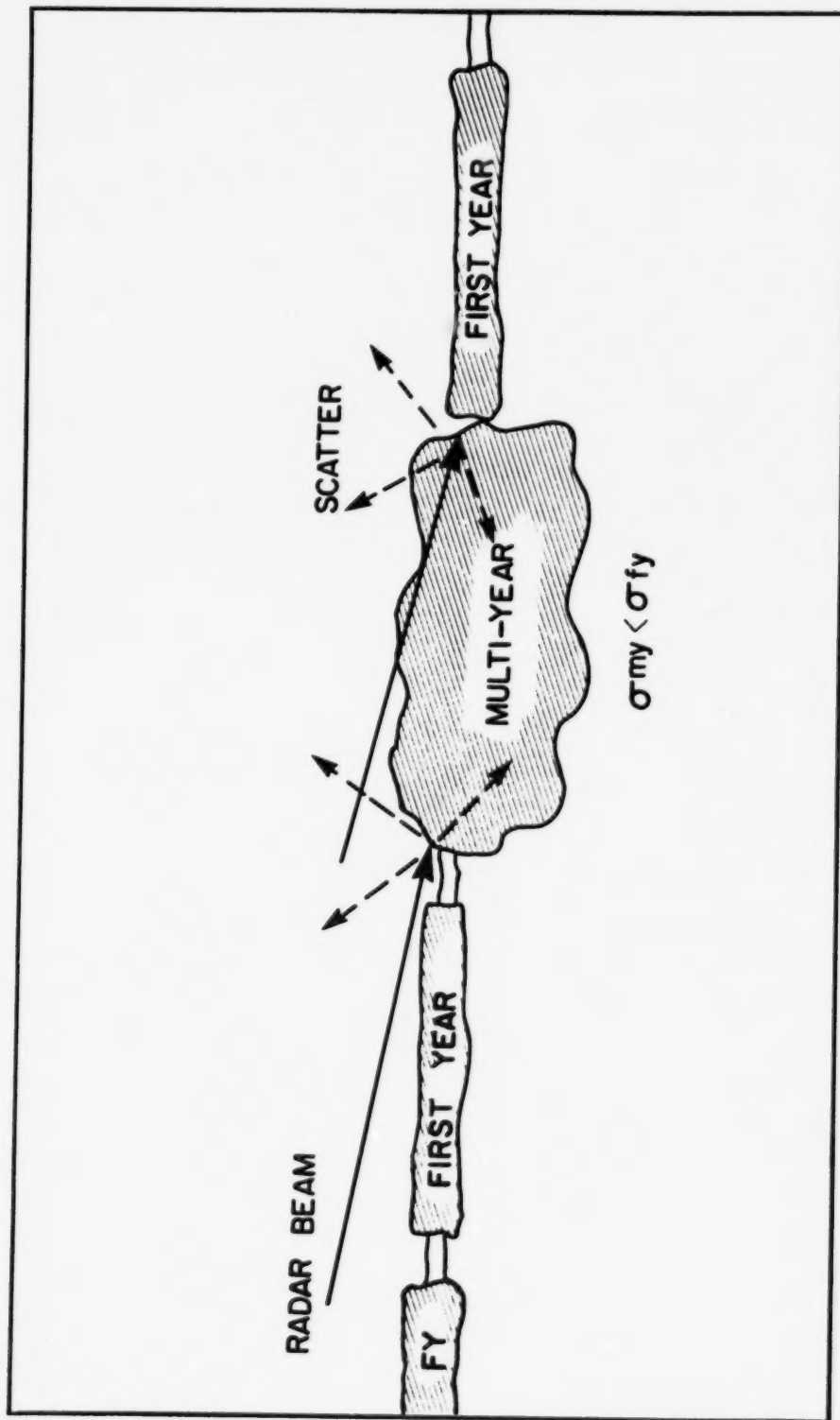


FIGURE 12. A pictorial treatment of multi-year floe acting to scatter the energy of an HF Transmission where σ_{my} and σ_{fy} represent conductivities of multiyear and first year sea ice respectively.

detection. The cross loop antenna portion was planned as a separate but collaborative contract to Ocean Surface Research Inc. of Woodside, Ca. but did not go ahead when the originally proposed funding did not materialize.

An analytical investigation has been started to support the iceberg detection and tracking program. It involves the application of special purpose signal processing techniques for the detection and tracking of a monochromatic signal return from such targets as icebergs and radar transponders. The prime objective of the study is to shorten the data collection time and to improve the instantaneous measurement of conditions.

The second project we had considered for the calander year 1983, to measure the backscatter from the interface between two types of ice, has now been postponed until a later date. Figure 12 illustrates how the electrical discontinuity of a multi-year floe would act to scatter an incident HF beam. Initially, we believe this experiment should be conducted over a well defined quiet test range, removed from any interference such as sea backscatter. The first issue to be resolved is the strength of the scattering from an ice/ice discontinuity; the possibility of sorting a multicomponent signal return is secondary. This is not to suggest that such interpretation is not tractable. Prospects for ocean/ice signal discrimination are good; ice returns will occur near zero Doppler separated from the main energy of the sea return in the frequency domain concentrated around the Bragg peaks. The test range selected should have a well formed cover of first year ice with an iceberg or multi-year floe trapped in

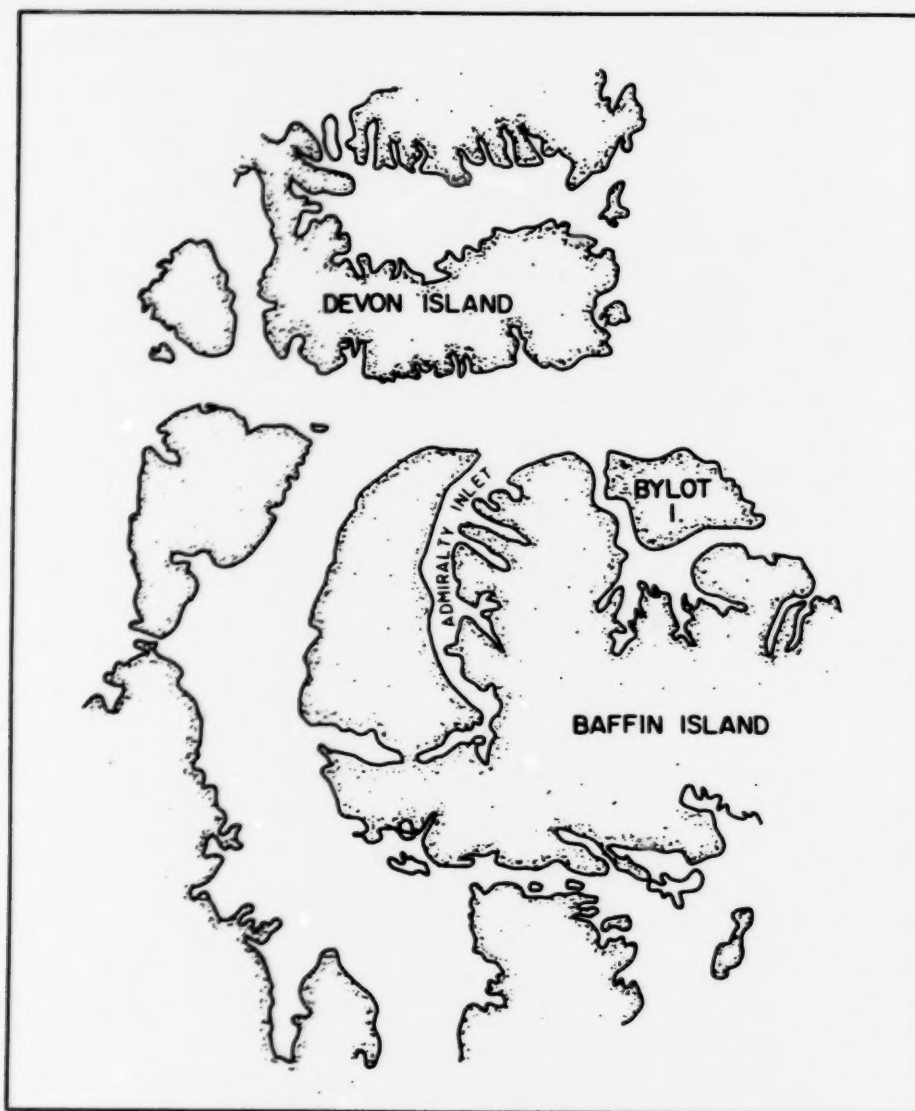


FIGURE 13. Map of northern Baffin Island, an area where there is a good chance of locating an iceberg or multi-year floes trapped in landfast first year ice to provide a site to experiment the detection of different ice types.

the ice. Such features would constitute a well defined discontinuity of ice types. Figure 13, a region of Northern Baffin Island, shows the various sounds and fiords which are a good prospective sites for the work. In addition, we will gather more data points on the propagation characteristics over an ice thickness at a different time of year from the 1982 work on attenuation of HF propagation over sea ice (Klein and Butt, 1983).

An experiment to detect and track the motion of an ice edge is slated for August 1984. The present proposal for the fieldwork is to arrange a site where we can observe polar pack ice from a coastal base over open water. The primary objective will be to measure the level of back and forward scattering of the HF surface wave from the water to ice interface. Figure 14 is a pictorial representation of the ice/water interface and how it will act to scatter a propagating EM wave. Also of interest is the backscattering effects from the opposite direction of ice to water. The Beaufort coast of the western arctic islands and the polar pack offer a potential field site for the ice edge experiment. Figure 15 is a map of the region under consideration. Ice edge monitoring and information on ice concentrations at the ice edge are important considerations of the ice reporting services and provide valuable information for offshore platform and vessel operators.

The experimental program definition is in its preliminary phase and it is very probably that new and different requirements will arise. Changes in this basic schedule of events will be necessary as the work progresses.

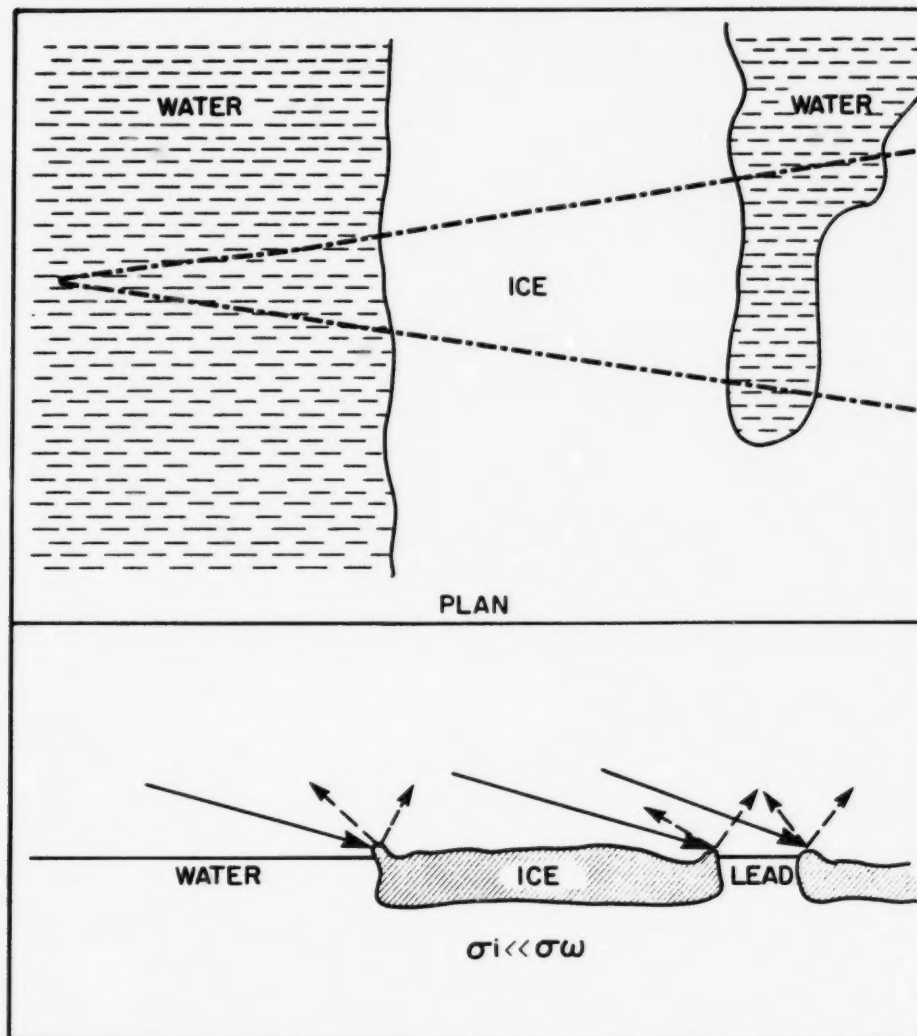


Figure 14. A pictorial treatment of an ice/water interface and the ice edges of a lead acting to scatter the energy of an HF transmission where σ_i and σ_w represent conductivities of sea ice and sea water respectively.

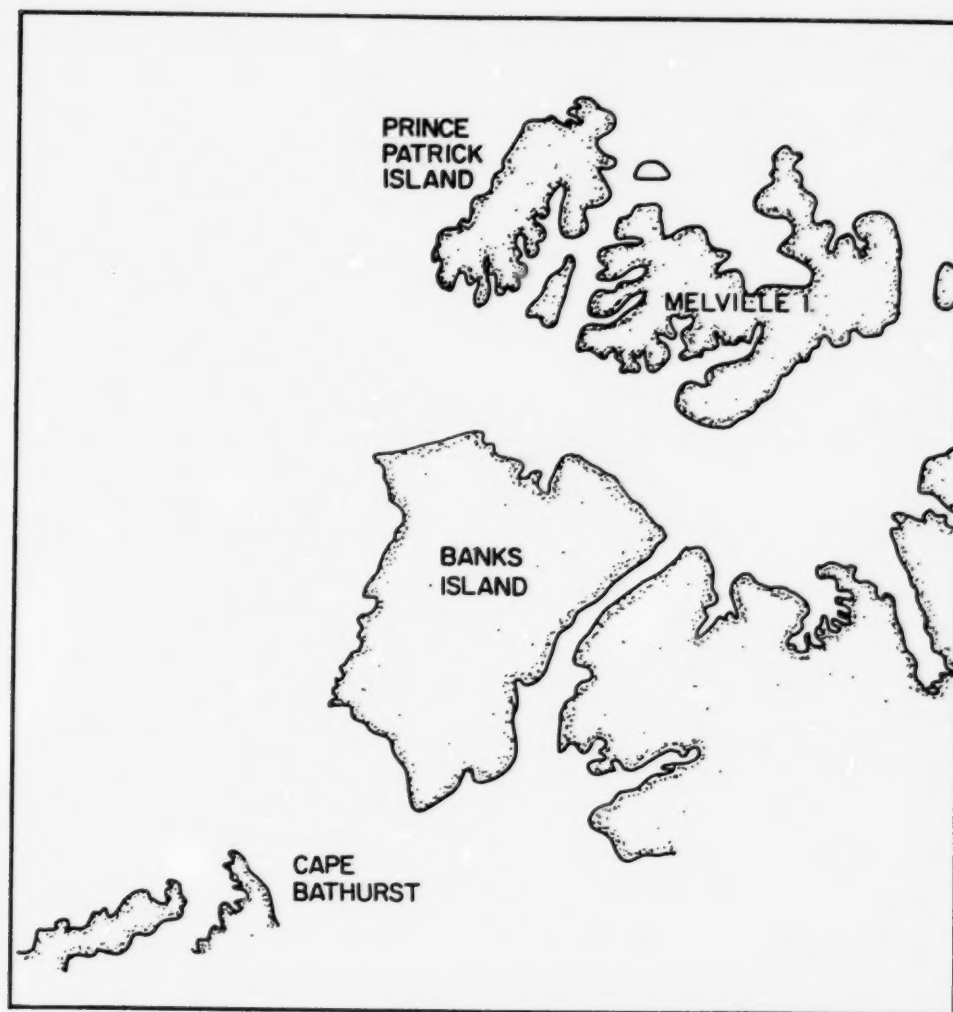


FIGURE 15. Map of the western Arctic islands where the polar pack offers a potential field site for the ice edge experiment with HF Radar.

5.0 PROJECT ORGANIZATION AND PARTICIPATION

The first milestone of the ice detection research program is to establish the scientific feasibility of the concept. Assuming a successful result it is important to plan for a systems engineering team to develop a prototype radar. We consider our program can be best achieved in a cooperative type venture between industry, government and university, using a flexible framework of commitment, rather than a rigid joint venture in the traditional North American sense. C-CORE has initiated the existing program with the help of the following: funding from Fisheries and Oceans directed to remote sensing of oceans; research contracts administered through Department of Supply and Service; C-CORE's general core funding and the support of the critical research groups. The mandate of the Centre is to serve as an intellectual and financial catalyst. The Canadian infrastructure for cost effective frontier research and development is fragile; in the National interest each principal actor must be given a chance to become involved.

The two initial components of the work are now nearing completion. The first was to develop the group's expertise to a state-of-the-art level in HF radar technology and the second was to equip the Centre with baseline radar hardware necessary to carry out the research. We presently plan to purchase the additional equipment needed for a second radar site. This will provide equipment backup for the ice radar research experiments as well as the capability to undertake surface current mapping and

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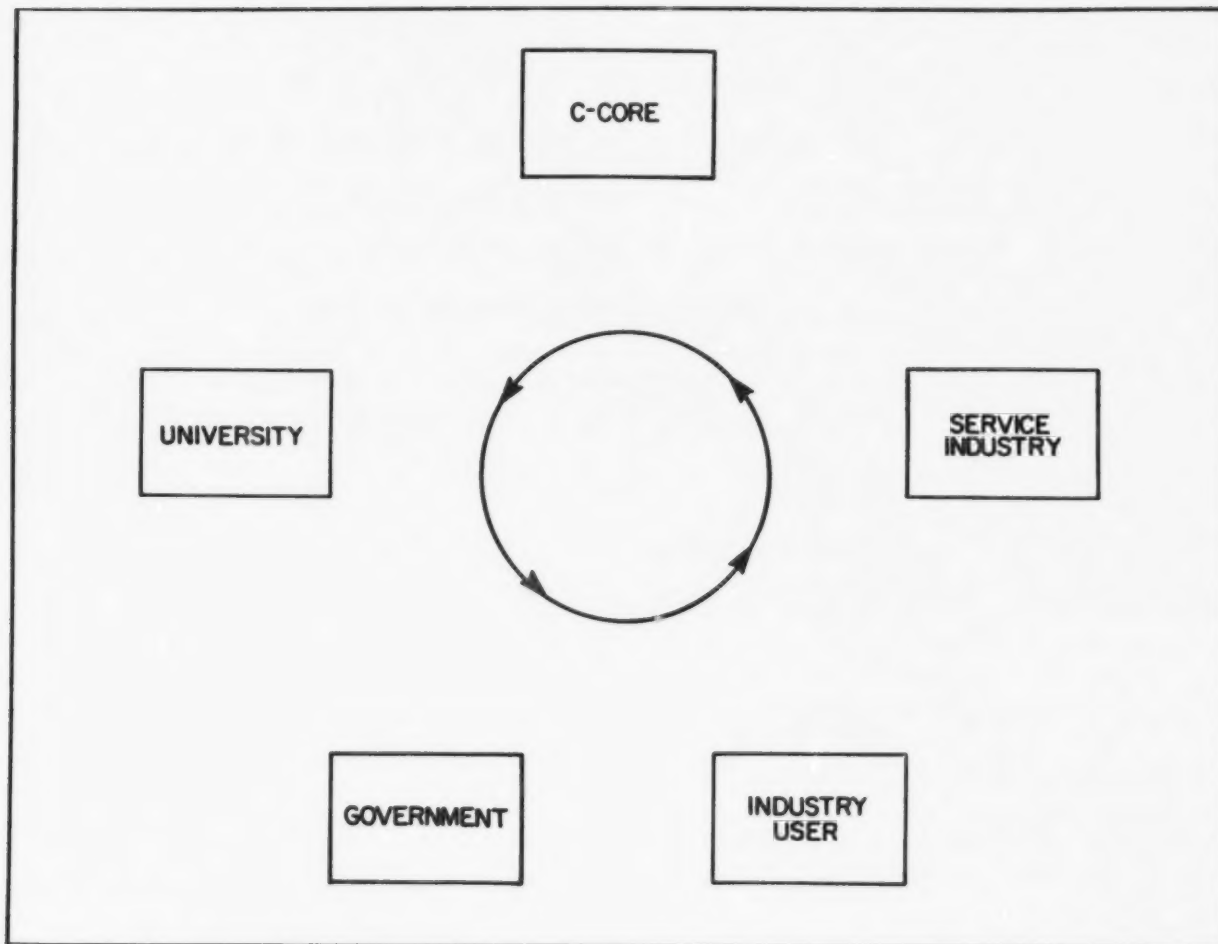


FIGURE 16. A schematic grouping of the various sectors involved in the HF radar research program.

transponder motion tracking from coastal locations. Transponders, active targets, can provide a stable reference for comparison in both motion and amplitude analysis of monochromatic targets such as sea ice and icebergs, distinct from ocean backscatter.

The work of C-CORE researchers and Memorial University's Engineering Faculty have complimented each other; the University has taken the lead in the theoretical work. The analytical requirements of the program provide excellent opportunities for graduate level research. Two students have completed Masters programs and the third will complete his PhD by the Spring of 1984. Two papers based on this work were presented at the International IEEE/APS Symposium and National Radio Science Meeting in May 1983 at the University of Houston. A joint C-CORE/Engineering application for an NSERC strategic grant was awarded to the University in November 1982 and continues for three years to support the research into the fundamental scientific issues involved in the radar program. The principle application of these funds will be to run a series of field experiments.

We have already generated a wide basis of intellectual support. Figure 16 sub-divides the various actors into a number of groups which are or are expected to be involved in some way. The NOAA Wave Propagation Laboratory, in the United States, has made its basic research results available and has provided copies of much of its processing software for our research program. Initially, Dr. Roger Stacey and now Dr. Don Lawrence of Fisheries and Oceans have offered their support as scientific authorities for our research project. We have shared visits and discussions

with a West German group who are also looking for applications in current measurements and for ice remote sensing. We plan to foster these contacts and make new ones during the International Workshop: The Remote Sensing of Ocean Variables Using HF Groundwave Radar to be held at Memorial University November 15-16, 1983, sponsored jointly by Fisheries and Oceans and C-CORE. The list of groups making presentations and of the topics they plan to cover is available for review in Appendix E.

Our contacts with industry, a potential user, have been intellectual so far with little direct financial support. We will not become involved in the engineering details of an ice detection system until we have assessed the initial results from this year's field experiments on the quality of the ice return signal including the spectral processing techniques required to provide high confidence signal to noise detection performance.

The interaction with the service industry has been developing in a number of ways. To date we have dealt with CODAR Technology Inc. of Boulder, Colo., a spin off from the NOAA Wave Propagation Laboratory. CTI Inc. supplied our present radar hardware and have provided consultation to instruct our staff on the basic operation. INSTRUMAR Ltd. of Newfoundland has been the principal supplier of specialized electronic interface development. Other Canadian companies will come on stream as some of the development work reaches the stage of more classical radio/radar equipment modification or redesign. Our dealings with local service companies will evolve as the program moves from research, to engineering and then to data collection or environmental

monitoring. The original iceberg proposal for example included Remotec Applications Inc. of Newfoundland and ORION Electronics Ltd. of Nova Scotia. When the system is ready to provide a survey service we hope that this function will be offered by one or a number of the oceanographic consultant and survey companies. The same could also hold for a ice hazard detection or ice monitoring, although it is most likely to take the form of product sales and installation services.

6.0 SUMMARY

The program can be sub-divided into a series of technical objectives.

(1) Make an initial evaluation of the existing HF radar systems and select one, CODAR, to provide the hardware basis to conduct our research. Develop the research team to operate the system and execute the field programs. Both of these can now be considered complete.

(2) Initiate a theoretical investigation of the scattering of groundwave propagation by a variety of ice features and ice conditions as targets. This work is well underway.

(3) Generate an experimental plan to investigate the potential of this type of radar to detect and monitor the progress of ice hazards and to monitor changing ice conditions.

The components of the program, including the execution of the required theoretical computations, the processing of the experimental data, and the formulation of conclusions and

recommendations based on the results must then be synthesized. The fundamental question is whether or not we can build a better ice detection system than is presently available or anticipated.

The radar system envisaged would be monostatic; the scattering process at HF does not appear to warrant the complexity and expense of going any other route. It would be terrestrially based equipment and would provide all weather and continuous coverage of a particular region. This is in contrast to airborne or satellite systems which could be incorporated to provide complementary information. The ground propagation at HF should provide over the horizon ranges in the order of 100 km. and allow the radar to provide large areal coverage of ocean conditions and the surface tracking of wind conditions, sea ice, icebergs and transponders. The target information would include range, bearing and velocity.

If the recommendation is positive and the risks are acceptable, it will be necessary to:

- (a) specify the equipment package required for the radar system,
- (b) specify the support software required to interpret the radar return and generate the information stream in a user format.

This could happen as a cooperative R&D program which would make available the required financial and intellectual resources needed to undertake the work. C-CORE does not claim to be able to tackle this sort of project on its own. Nor do we want to divert our research direction to formulate such a program. We are

confident that we can act as the focal point for the resources of a number of organizations which will work together to do the work. We are sure there is Canadian expertise capable of carrying out the proposed research and of implementing the results to produce an economical remote sensing system that will service a number of important ocean engineering and oceanographic needs.

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APPENDIX A

CHRONOLOGICAL ORDER OF THE EVENTS OF THE FIELD PROGRAM

- Oct. 18/ 82 Departure (9:00) of field personnel and equipment.
Arrival (12:00) at Northern Bay Sands (experimental test site)
Assembly and testing of CODAR system
Partial assembly of 24 element receive antenna (80%).
- Oct. 19/ 82 Assembly of 24 element array completed.
Installation of Waverider Buoy and telemetry system.
Preliminary sea state data collection.
- Oct. 20/ 82 First collection of beam pattern using transponder data.
Calculation of normalized antenna pattern.
Collection of sea state data.
- Oct. 21/ 82 Collection of transponder data for estimation of HF propagation loss over sea water with range.
Collection of sea state data.
Trouble shooting and repair 24 element area with field strength meter (2 elements down).
- Oct. 22/ 82 Repeat of beam pattern measurements using transponder.
Collection of sea state data.
Calculation of normalized antenna pattern.
Measurement of 24 element antenna using field strength meter.
System shut down pending change of sea state.
Departure of most field personnel back to St. John's.
- Oct. 27/ 82 Return of personnel to test site. System brought up.
Measurement of 24 element antenna using field strength meter.
Installation of analogue recording of waverider data to augment existing system.
24 hour collection of sea state data begun.
Collection of wind speed/direction data.
- Oct. 28/ 82 24 hour collection of sea state data completed.
Collection of wind speed/direction data completed.
Removal of waverider buoy.
Complete shut down of system.
Dismantling of equipment begun.
- Oct. 29/ 82 Dismantling of equipment completed.
Return of all equipment and personnel to St. John's.

APPENDIX B

THE POSITIONAL COORDINATES FOR THE MAPPING LINES

Waverider installation:

October 19, 1982

Waverider buoy anchorage (Radar measurements from boat)

3.75 miles from Western Bay Head

2.1 miles from Jobes Cove

3.5 miles from Northern Bay Sands

24 Element Array Beam Pattern Data Catalogue:

i) October 20, 1982

Transit Readings Initial/ Final	Distance from Northern Bay Sands Beach (km)	Distance from Western Bay Head (km)	Distance from Job's Cove (km)	Wind Speed kph	Start Time (2 min. per locat.)
52°52' / 52°30'	5.6	5.6	5.7	29	9.46
51°00' / 49°30'	5.6	5.9	5.2	29	
49°10' / 49°00'	5.6	5.9	5.2	23	10:15
49°30' / 49°48'	5.6	5.9	5.2	29	10:22
46°40' / 47°00'	5.6	6.0	4.8	29	10:31
44°49' / 45°17'	5.6	6.1	4.6	26	10:40
42°40' / 42°45'	5.6	6.3	4.2	26	10:50
39°39' / 39°35'	5.6	6.5	4.1	17	11:00
37°13' / 37°11'	5.6	6.7	3.9	13	11:20
34°37' / 34°37'	5.6	6.9	3.7	17	11:31
31°43' / 31°08'	5.6	7.2	3.2	29	12:20
28°15' / 27°30'	5.6	7.4	3.0	30	12:31
25°10' / 24°41'	5.6	7.6	2.8	29	12:40
23°02' / 23°14'	5.6	7.8	2.6	30	12:51
20°48' / 20°42'	5.6	8.0	2.3	26	13:02
18°43' / 18°27'	5.6	8.2	2.0	30	13:11
17°04' / 17°14'	5.6	8.3	1.9	29	13:21
15°18' / 15°29'	5.6	8.3	1.7	29	13:31
13°05' / 13°26'	5.6	8.3	1.5	34	13:40
11°00' / 11°24'	5.6	8.3	1.3	30	13:50
10°00' / 9°52'	5.6	8.3	1.1	32	14:00

*Note: Distance measurements were made with marine radar on the vessel carrying HF transponder. Wind velocity measurements were made with anemometer on same vessel.

APPENDIX B (continued)

October 21

HF attenuation over sea water: vessel position data catalogue.

Distance from Northern Bay Sands Beach n. miles	Distance from Western Bay Head (km)	Distance from Job's Cove (km)	Wind speed kph	Time
1.0	5.2	2.8	29	10.45
2.0	5.7	3.9	32	
3.0	6.5	4.1	36	11.16
4.0	7.9	6.9	37	11.31
5.0	9.3	6.5	32	
6.0	11.5	8.2	43	11.59
7.0	12.8	9.6	21	12.14
distance from Bay de Verde				
8.0	14.1	16.5	26	12.43
9.0	16.2	16.7	19	12.53
Cape St. Francis				
10.0	14.5	17.6	32	1.13
Bacculieu Island				
11.0	14.8	17.6	29	1.31
12.0	14.6	18.7	28	1.45

APPENDIX B (continued)

October 22, 1982

Transit Reading Initial/ Final	Distance from Northern Bay Sands (km)	Distance from Western Bay Head (km)	Distance from Job's Cove (km)	Wind Speed kph	Start time 2 mins/ Locat.

15°00'/15°05'	5.6	5.3	5.7	32	9:37
12°26'/12°04'	5.6	5.6	5.4	32	9:45
11°14'/11°08'	5.6	5.7	5.2	32	9:51
8°58'/8°45'	5.6	5.9	5.0	29	9:59
7°59'/7°52'	5.6	5.9	5.0	29	10:05
7°43'/7°12'	5.6	5.9	5.0	26	10:09
7°06'/5°35'	5.6	5.9	5.0	26	10:14
8°02'/8°01'	5.6	5.8	5.1	29	10:25
6°55'/6°32'	5.6	5.9	4.8	26	10:32
3°51'/3°41'	5.6	6.0	4.4	26	10:44
2°52'/2°36'	5.6	6.2	4.3	29	10:50
1°05'/1°06'	5.6	6.4	4.3	45	10:56
359°49'/359°30'	5.6	6.5	4.2	45	11:02
357°07'/356°36'	5.6	6.7	3.9	43	11:08
355°20'/354°59'	5.6	6.9	3.7	36	11:14
353°15'/353°02'	5.6	7.0	3.5	32	11:20
351°40'/351°15'	5.6	7.2	3.3	32	11:25
349°55'/349°41'	5.6	7.3	3.2	28	11:32
348°38'/348°19'	5.6	7.4	3.2	32	11:37
347°51'/347°32'	5.6	7.6	3.1	36	11:45
346°32'/346°19'	5.6	7.7	2.8	29	11:50
345°03'/344°41'	5.6	7.8	2.7	29	11:55
343°10'/342°50'	5.6	7.9	2.4	29	12:01
341°04'/340°50'	5.7	8.0	2.3	34	12:06
339°00'/338°47'	5.7	8.0	2.1	40	12:12
334°59'/334°47'	5.7	8.2	1.6	45	12:20
333°04'/333°03'	5.7	8.2	1.3	44	12:26

*Note: Distance measurements were made with marine radar on vessel carrying HF transponder. Wind velocity measurements were made with anemometer on same vessel.

Wind Speed and Direction Data Catalogue

October 22, 1982

Vessel Location: Wave Rider Buoy

i)	TIME	SPEED kph	DIRECTION
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	12.50	35 - 39	NW
	12.52	39 - 42	NW
	12.54	39 - 42	NW
	12.56	35 - 39	NW
	12.58	32 - 35	NW
	1.00	39 - 42	NW
	1.02	42 - 45	NW
	1.04	32 - 35	NW
	1.06	32 - 35	NW
	1.08	35 - 39	NW
	1.10	39 - 42	NW
	1.12	39 - 42	NW
	1.14	42 - 48	NW

*Note: Distance measurements were made with marine radar on vessel carrying HF transponder. Wind velocity measurements were made with anemometer on same vessel.

APPENDIX B (continued)

ii) October 27, 1982

WIND SPEED AND DIRECTION

Speed now in metres/second

Direction in degrees from magnetic north

TIME	DIRECTION	SPEED
3.48	290°	4-5 m/s
3.50	290°	4-5 m/s
3.55	290°	4 m/s
4.00	290°	3 m/s
4.05	290°	5 m/s
4.10	290°	3 m/s
4.15	290°	4 m/s

*Note: Distance measurements were made with marine radar on vessel carrying HF transponder. Wind velocity measurements were made with anemometer on same vessel.

APPENDIX B (continued)

iii) October 28, 1982

TIME	DIRECTION	SPEED	TIME	DIRECTION	SPEED
9.00	290°	1 m/s	11.35	220	2.0 m/s
9.05	290°	2 m/s	11.40	210	1.5 m/s
9.10	290°	2 m/s	11.45	210	3.5 m/s
9.15	290°	2 m/s	11.50	210	1.5 m/s
9.20	290°	2.5 m/s	11.55	210	1.5 m/s
9.25	290°	1.5 m/s	12.00	220	1.0 m/s
9.30	290°	2.0 m/s	12.05	220	3.0 m/s
9.35	290°	2.0 m/s	12.10	210	4.0 m/s
9.40	290°	1.5 m/s	12.15	200	3.0 m/s
9.45	290°	1.0 m/s	12.20	190	4.0 m/s
9.50	290°	0.5 m/s	12.25	200	3.0 m/s
9.55	290°	1.5 m/s	12.30	190	2.5 m/s
10.00	290°	0.25 m/s	12.35	200	2.5 m/s
10.05	0°	0	12.40	210	3.5 m/s
10.10	290°	1.0 m/s	12.45	200	2.5 m/s
10.15	260°	0.5 m/s	12.50	200	2.5 m/s
10.20	0°	0	12.55	190	2.5 m/s
10.25	0°	0	1.00	180	3.0 m/s
10.30	0°	0	1.05	190	4.0 m/s
10.35	270°	1.5 m/s	1.10	210	3.0 m/s
10.40	200°	1.0 m/s	1.15	200	5.0 m/s
10.45	210°	1.5 m/s	1.20	200	3.5 m/s
10.50	200°	1.5 m/s	1.25	200	4.0 m/s
10.55	200°	0.25 m/s	1.30	200	4.5 m/s
11.00	180°	1.0 m/s	1.35	190	4.5 m/s
11.05	170°	2.0 m/s	1.40	190	5.0 m/s
11.10	210°	3.0 m/s	1.45	190	3.5 m/s
11.15	210°	1.5 m/s	1.50	190	6.0 m/s
11.20	240°	3.0 m/s	1.55	190	6.0 m/s
11.25	210°	3.0 m/s	2.00	190	5.5 m/s
11.30	210°	2.0 m/s			

*Note: Distance measurements were made with marine radar on vessel carrying HF transponder. Wind velocity measurements were made with anemometer on same vessel.

APPENDIX C
CATALOGUE OF THE WAVERIDER BUOY DATA

Strip Chart Records

i) Strip chart Recordings		5 - 0 - 5 m scale		
Start		Stop	Chart Interval	
16:47	Oct. 19/ 82	17:21 Oct. 19/ 82	02 to 36	
9:16	Oct. 20/ 82	01:01 Oct. 21/ 82	44 to 990	
11:48	Oct. 21/ 82	15:32 Oct. 21/ 82	21 to 243	
16:15	Oct. 21/ 82	16:51 Oct. 21/ 82	245 to 281	
9:04	Oct. 22/ 82	13:53 Oct. 22/ 82	327 to 616	
19:39	Oct. 22/ 82	19:45 Oct. 22/ 82	617 to 623	
8:51	Oct. 23/ 82	8:57 Oct. 23/ 82	624 to 630	
11:10	Oct. 23/ 82	11:14 Oct. 23/ 82	632 to 636	
14:43	Oct. 23/ 82	14:48 Oct. 23/ 82	636 to 641	
6:55	Oct. 24/ 82	7:30 Oct. 24/ 82	642 to 677	

Cassette Records

ii) Warep Digital Recordings (Cassette)

Tape #	Start	Stop
1	17:01 Oct. 19/ 82	17:21 Oct. 19/ 82
	9:16 Oct. 20/ 82	10:56 Oct. 20/ 82
	10:56 Oct. 20/ 82	13:39 Oct. 20/ 82
	13:39 Oct. 20/ 82	12:00 Oct. 21/ 82
2	12:00 Oct. 21/ 82	19:39 Oct. 22/ 82
3	11:00 Oct. 27/ 82	14:24 Oct. 28/ 82

Note: Warep set on 5-0-5 m scale throughout recording intervals. Calibrations using 3-0-3 m signals were placed at selected intervals on both strip chart and analogue recordings.

APPENDIX C (continued)

Analogue Recordings

iii) Racal Store 4 Analogue recordings (15/16 ips)					
Tape	Start	Stop	Recording Scale	Approximate Tape Location	
A	11:23 Oct. 27/ 82	18:47 Oct. 27/ 82	5V	13-750	
			2V	750-2090	
B	18:57 Oct. 27/ 82	2:00 Oct. 28/ 82	2V	5-2031	
C	2:10 Oct. 28/ 82	10:25 Oct. 28/ 82	2V	0-2275	
D	10:33 Oct. 28/ 82	14:18 Oct. 28/ 82	2V	0-1040	

APPENDIX D

THE CATALOGUE OF THE RADAR TAPES

TAPE RUN I.D.	DATE	N FFT size = 2n	FREQUENCY (MHz)	PULSE WIDTH sec	COMMENTS
AA01	19/10/82	9	25.4	16	Operational Test
AA02	19/10/82	9	25.4	16	
AA03	19/10/82	9	25.4	8	
AA04	19/10/82	9	25.4	8	Sea State Runs Significant Interference
AA05	19/10/82	9	25.4	8	Observed Offshore Wind at approx. 30 knots
AA06	19/10/82	11	25.4	8	
AA07	19/10/82	11	25.4	8	Sea State Run: Wind Dropping off
AB02	20/10/82	9	25.4	16	
AB03	20/10/82	9	25.4	16	
AB04	20/10/82	9	25.4	16	
AB05	20/10/82	9	25.4	16	
AB06	20/10/82	9	25.4	16	
AB07	20/10/82	9	25.4	16	
AB08	20/10/82	9	25.4	16	First Mapping Receive Antenna
AB09	20/10/82	9	25.4	16	Beam Pattern with Transponder

TAPE RUN I.D.	DATE	N FFT size = 2n	FREQUENCY (MHz)	PULSE WIDTH sec	COMMENTS
AB10	20/10/82	9	25.4	16	
AB11	20/10/82	9	25.4	16	
AB12	20/10/82	9	25.4	16	
AB13	20/10/82	9	25.4	16	
AB14	20/10/82	9	25.4	16	
AB15	20/10/82	9	25.4	16	
AC01	20/10/82	9	25.4	16	
AC02	20/10/82	9	25.4	16	
AC03	20/10/82	9	25.4	16	
AC04	20/10/82	9	25.4	16	
AC05	20/10/82	9	25.4	16	First Mapping Receive Antenna
AC06	20/10/82	9	25.4	16	Beam Pattern with Transponder
AC07	20/10/82	9	25.4	16	
AC08	20/10/82	9	25.4	16	
AC09	20/10/82	9	25.4	16	

TAPE RUN I.D.	DATE	N FFT size = 2n	FREQUENCY (MHz)	PULSE WIDTH sec	COMMENTS
AC10	20/10/82	9	25.4	16	
AC11	20/10/82	9	25.4	16	
AD01	20/10/82	12	25.4	8	Sea State Run Sporadic Interference
AE01	20/10/82	12	25.4	8	Sea State Run
AF01	21/10/82	9	25.4	16	Attenuation over Sea Water using
AF02	21/10/82	9	25.4	16	Transponder. Transponder off course.
AF03	21/10/82	9	25.4	16	
AF04	21/10/82	9	25.4	16	
AF05	21/10/82	9	25.4	16	
AF06	21/10/82	9	25.4	16	Attenuation over Sea Water using
AF07	21/10/82	9	25.4	16	Transponder. Transponder on course.
AF08	21/10/82	9	25.4	16	Transponder on course.
AF09	21/10/82	9	25.4	16	
AF10	21/10/82	9	25.4	16	

TAPE RUN I.D.	DATE	N FFT size = 2n	FREQUENCY (MHz)	PULSE WIDTH sec	COMMENTS
AF11	21/10/82	9	25.4	16	Attenuation over Sea
AF12	21/10/82	9	25.4	16	Water using Transponder
AF13	21/10/82	9	25.4	16	
AG02	21/10/82	9	25.4	16	
AG03	21/10/82	9	25.4	16	Attenuation over sea
AG04	21/10/82	9	25.4	16	Water using Transponder
AG05	21/10/82	9	25.4	16	
AH01	21/10/82	10	25.4	8	
	Sea State Run				
AH02	21/10/82	12	25.4	8	
AI02	22/10/82	9	25.4	16	Operational testing prior to
AI03	22/10/82	10	25.4	16	beginning second measurement
AI04	22/10/82	9	25.4	16	of beam pattern
AI05	22/10/82	9	25.4	16	

TAPE RUN I.D.	DATE	N FFT size = 2n	FREQUENCY (MHz)	PULSE WIDTH sec	COMMENTS
AI06	22/10/82	9	25.4	16	
AI07	22/10/82	9	25.4	16	
AI08	22/10/82	9	25.4	16	Second Mapping of Receive Antenna
AI09	22/10/82	9	25.4	16	Beam Pattern with Transponder.
AI10	22/10/82	9	25.4	16	
AI11	22/10/82	9	25.4	16	
AJ01	22/10/82	9	25.4	16	
AJ02	22/10/82	9	25.4	16	
AJ03	22/10.82	9	25.4	16	
AJ04	22/10/82	9	25.4	16	
AJ05	22/10/82	9	25.4	16	
AJ06	22/10/82	9	25.4	16	
AJ07	22/10/82	9	25.4	16	
AJ08	22/10/82	9	25.4	16	
AJ09	22/10/82	9	25.4	16	

TAPE RUN I.D.	DATE	N FFT size = 2n	FREQUENCY (MHz)	PULSE WIDTH sec	COMMENTS
AJ10	22/10/82	9	25.4	16	
AJ11	22/10/82	9	25.4	16	Second Mapping of Receive Antenna
AJ12	22/10/82	9	25.4	16	Beam Pattern with Transponder
AK01	22/10/82	9	25.4	16	
AK02	22/10/82	9	25.4	16	
AK03	22/10/82	9	25.4	16	
AK04	22/10/82	9	25.4	16	
AK05	22/10/82	9	25.4	16	
AK06	22/10/82	9	25.4	16	
AK07	22/10/82	9	25.4	16	
AK08	22/10/82	9	25.4	16	
AL01	22/10/82	12	25.4	8	Sea State Run. Tide going out.
AM01	22/10/82	12	25.4	8	Sea State Run. Communications Interference
AN01	27/10/82	12	25.4	8	

TAPE RUN I.D.	DATE	N FFT size = 2n	FREQUENCY (MHz)	PULSE WIDTH sec	COMMENTS
AO01	27/10/82	12	25.4	8	
AO02	27/10/82	12	25.4	8	
AO03	27/10/82	12	25.4	8	
AO04	27/10/82	12	25.4	8	
AO05	27/10/82	12	25.4	8	
AP01	27/10/82	12	25.4	8	
Collection of Sea State data					
AQ01	27/10/82	12	25.4	8	over 24 hour period
AQ02	28/10/82	12	25.4	8	
AQ03	28/10/82	12	25.4	8	
AQ04	28/10/82	12	25.4	8	
AQ05	28/10/82	12	25.4	8	
AR01	28/10/82	12	25.4	8	
AR02	28/10/82	12	25.4	8	
AR03	28/10/82	12	25.4	8	

TAPE RUN I.D.	DATE	N FFT size = 2n	FREQUENCY (MHz)	PULSE WIDTH sec	COMMENTS
AR04	28/10/82	12	25.4	8	
AR05	28/10/82	12	25.4	8	
AS01	28/10/82	12	25.4	8	
AS02	28/10/82	12	25.4	8	
AS03	28/10/82	12	25.4	8	
AS04	28/10/82	12	25.4	8	
AS05	28/10/82	12	25.4	8	
Collection of Sea State over 24 hour period					
AT01	28/10/82	12	25.4	8	
AT02	28/10/82	12	25.4	8	
AT04	28/10/82	12	25.1	8	
AT05	28/10/82	12	25.1	8	
AT06	28/10/82	12	25.1	8	

TAPE RUN I.D.	DATE	N FFT size = 2n	FREQUENCY (MHz)	PULSE WIDTH sec	COMMENTS
					Frequency change. Collection of Sea State
AU01	28/10/82	12	25.1	8	over 24 hour period
AV01	28/10/82	12	25.1	8	
AW01	28/10/82	12	25.1	8	
AX01	28/10/82	12	25.1	8	

APPENDIX E

TOPIC LIST FOR THE NOVEMBER WORKSHOP

International Workshop on the Remote Sensing of Oceanic Variables
Using HF Groundwave Radar

C-CORE
Memorial University of Newfoundland
St. John's, Newfoundland
November 1983

Tentative Presentations:

The Titles and/or Topics For Discussion by Group.

Centre for Cold Ocean Resources Engineering / Ocean Engineering,
Memorial University of Newfoundland, St. John's, Newfoundland,
Canada.

- a. Remote Estimation of Ocean Surface Currents Off Canada's East Coast Using HF Doppler Radar.
- b. Results of an Experiment to Determine the HF EM Surface Wave Radar Cross Section of Icebergs.
- c. Propagation of HF EM Surface Waves Over Uniform First Year Sea Ice.
- d. Analytic Estimation of the Continuous Doppler Spectrum from a Knowledge of the Ocean Directional Wave Height Spectrum.
- e. Discussion of an Analysis of the Application of Maximum Entropy Spectral Analysis to HF Doppler Transponder Tracking.
- f. Development of a High Sensitivity Doppler Transponder Control System.
- g. Overall Application of HF Doppler Radar for the Remote Sensing of Ocean Ice.

National Oceanic and Atmospheric Administration, Wave Propagation
Laboratory, Environmental Research Laboratories, Boulder,
Colorado, U.S.A.

- a. Overview of the Coastal Ocean Dynamics Application Radar (CODAR) System Documentation.
- b. Overview of Development of a Real Time Multi-Site CODAR System within NOAA.
- c. Standardization of Processing Software for NOAA Surface Current Data Sets.
- d. Implementation of a Hybrid Angle Algorithm for Signal Detection with Error Estimates.
- e. Use of Spatial Current Coefficients for Continuity Equations and Data Reduction.

APPENDIX (continued)

CODAR Technology Incorporated, Longmont, Colorado, U.S.A.

- a. Overview of CODAR Hardware Systems and Associated Technology.
- b. Results of an HF Radar Experiment to Test the Feasibility of Applying HF Doppler Transponders to the Tracking of Low Velocity Sea Ice.

Ocean Surface Research Inc., Woodside, California, U.S.A.

- a. Measurement of Ocean Surface Currents and Wave Fields Using CODAR with a Cross-Loop/Monopole Antenna.

Institut fur Meereskunde, Universitat Hamburg, Hamburg, Federal Republic of Germany.

- a. Experience with EM Interference Between 25 and 400 MHz in the North Sea and Baltic.
- b. HF EM Propagation Over Sea Ice in the Baltic and Fram Strait.
- c. Experimental Results on Attenuation and Backscatter of EM Waves Over Sea at Different Frequencies.
- d. Near Shore Currents in the Baltic Using HF Doppler Radar.

Department of Electronic & Electrical Engineering, University of Birmingham, Birmingham, England

- a. Groundwave HF Doppler Radar Ocean Wave Measurement Experiments in the United Kingdom.
- b. Technology of a Frequency Modulated Interrupted Continuous Wave (FMICW) HF Doppler Radar for Remote Sensing of the Ocean Surface.

Appleton Laboratory, Slough, England.

- a. Interpretation of Wave/Wind Interaction for HF Sea State Mapping.
- b. Experimental Results Using Pulsed CW HF Doppler Radar for Surface Current Measurements in the United Kingdom.

POOR

QUALITY

ORIGINAL